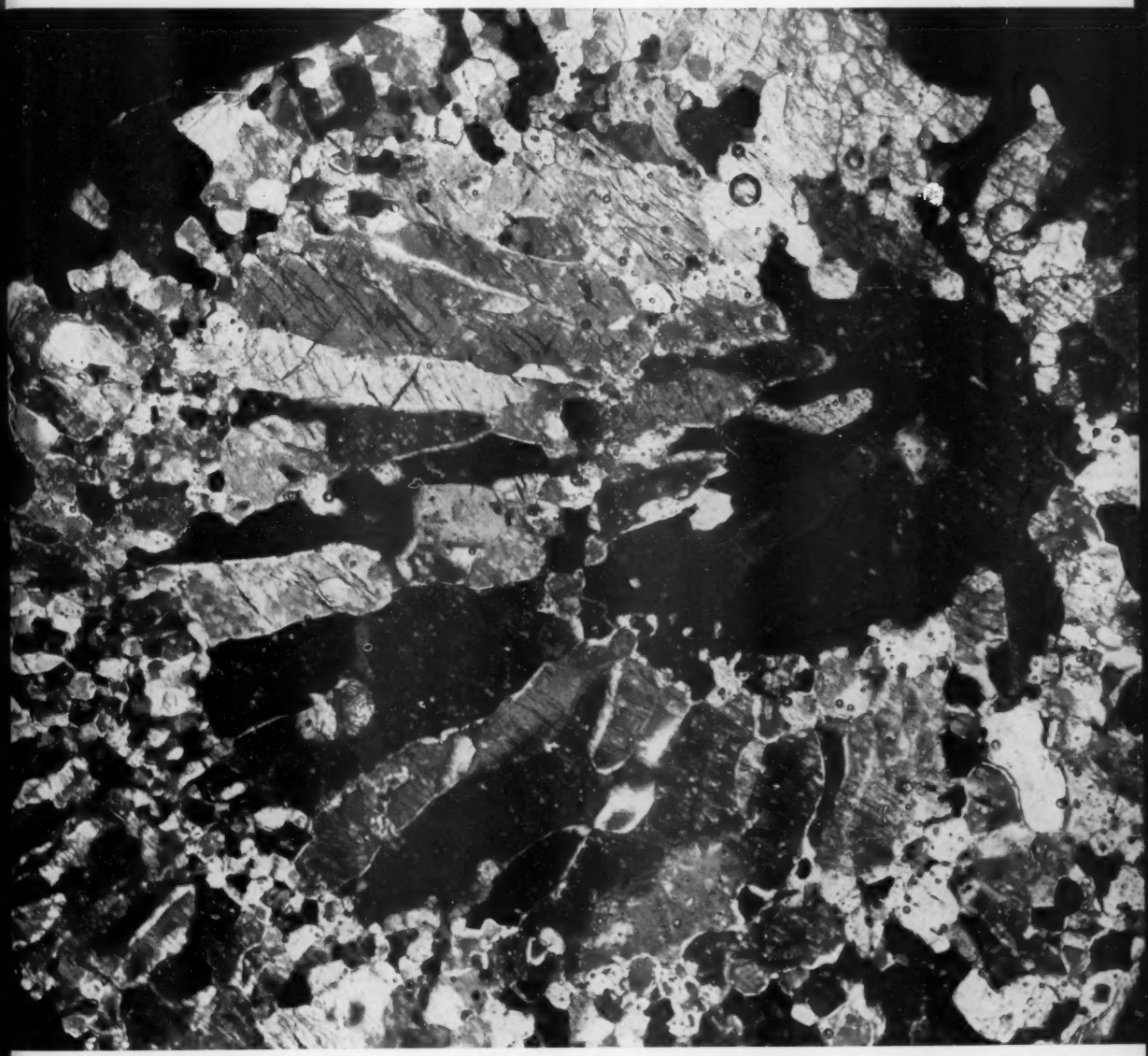
SCIENCE

21 October 1960

Vol. 132, No. 3434

AMERICAN ASSOCIATION FOR THE ADVANCEMENT OF SCIENCE



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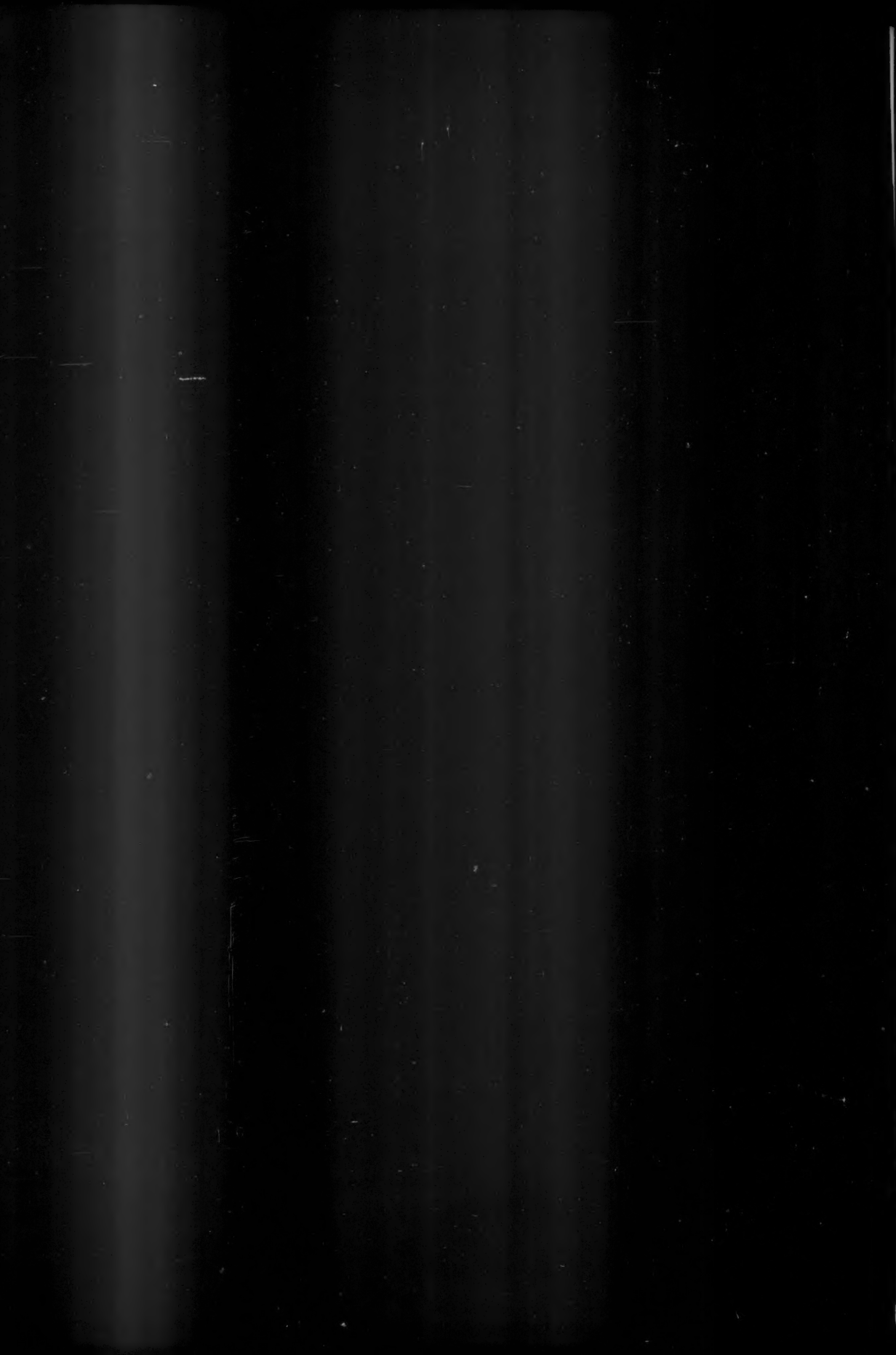

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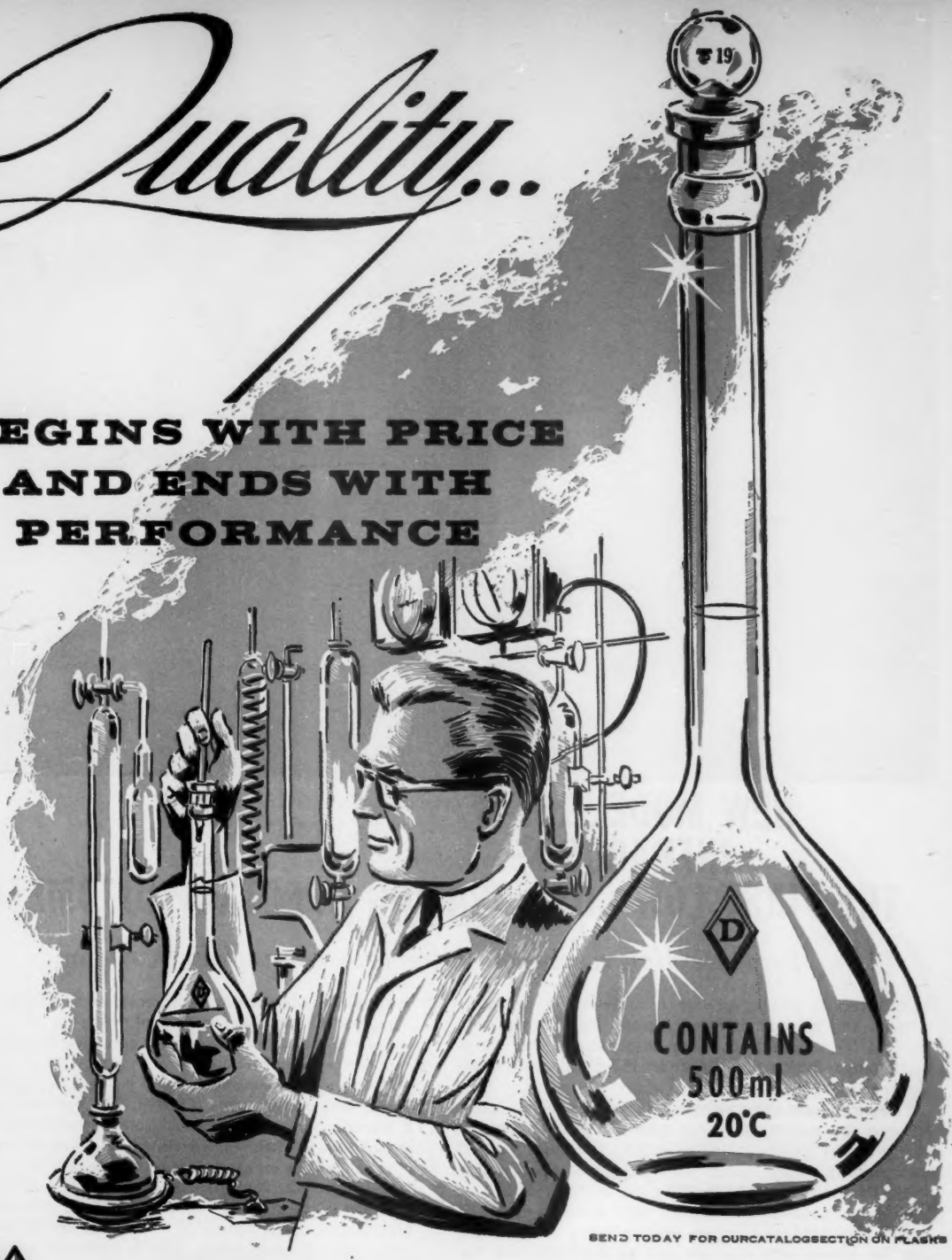

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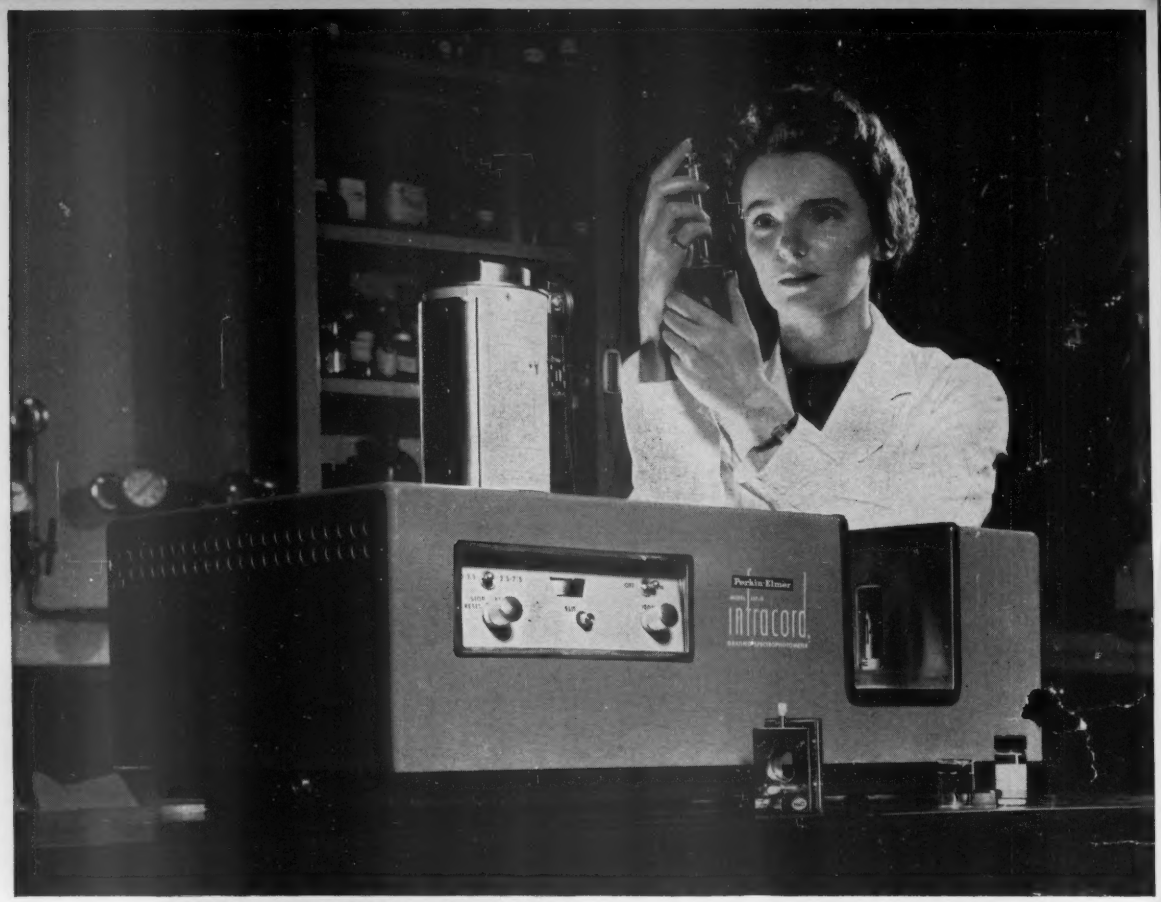

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The instrument offers wide application for accurate measurement of spectral transmission, specular reflectance and wavelength cutoff values of a wide variety of filters and other optical components. This is especially important in the military infrared field.

For further information, including performance data, write Perkin-Elmer Corporation, 910 Main Avenue, Norwalk, Connecticut.

INSTRUMENT DIVISION

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21 October 1960, Volume 132, Number 3434

SCIENCE

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Artificial production of hailstones leads to advances in the understanding of their natural formation.

Searching Natural Language Text by Computer: *D. R. Swanson* 1099
Machine indexing and text searching offer an approach to the basic problems of library automation.

Modern Blasting Agents: *M. A. Cook* 1105
Because they are safer, cheaper, and nontoxic, they are replacing dynamites in some operations.

A Computer Program for Classifying Plants: *D. J. Rogers* and *T. T. Tanimoto* 1115
The computer is programmed to simulate the taxonomic process of comparing each case with every other case.

Photoelectric Photometry in Astronomical Studies: *F. B. Wood* 1123
Advances have been made in various fields of astronomy through the use of photoelectric techniques.

Integration of Circuit Functions into Solids: *S. W. Herwald* and *S. J. Angello* 1127
The trend in electronic circuit construction is toward microminiaturization and molecular electronics.

Photographic Tracking of Elementary Particles: *C. F. Powell* 1134
Sheets of emulsion can be stacked so that the tracks of particles can be recorded in three dimensions.

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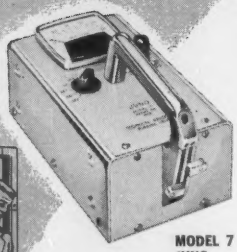
Cover Thin section of hailstone with polarized light. See page 1091.

T/A

Instruments and Systems for Nuclear Research and Radiation Measurements

HEALTH PHYSICS

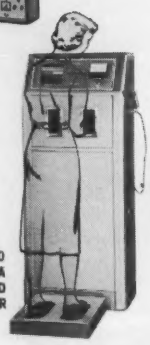
For many years, T/A has led in the development of personnel monitors for the automatic detection and measurement of radiation contamination. T/A portable survey meters are the most widely used radiation survey meters in the world.



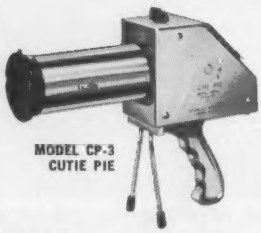
MODEL 7 JUNO

- Juno Survey Meter
- Cutie Pie Survey Meter
- Beta-Gamma Hand and Shoe Monitors
- Portal Monitor
- Alpha Hand Monitors
- Laundry Monitor

MODEL PPM-8 PORTAL MONITOR



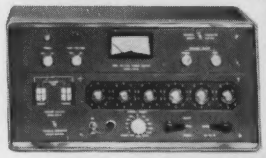
MODEL HSM-10 BETA-GAMMA HAND AND SHOE MONITOR



MODEL CP-3 CUTIE PIE

COUNTING & ANALYTICAL SYSTEMS

MODEL GTS-6 SCALER shown with Model RHV-3 5000 Volt Power Supply



High speed decade scaler has pulse resolution better than 1 microsecond. Model RHV-3 H.V. Supply is used for Geiger and proportional counting.

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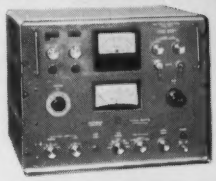

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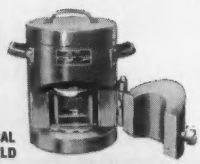

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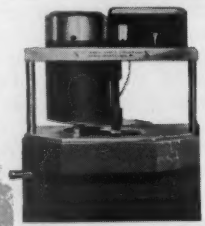

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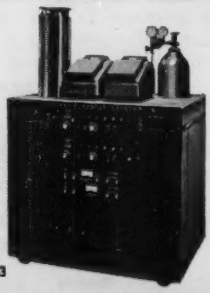

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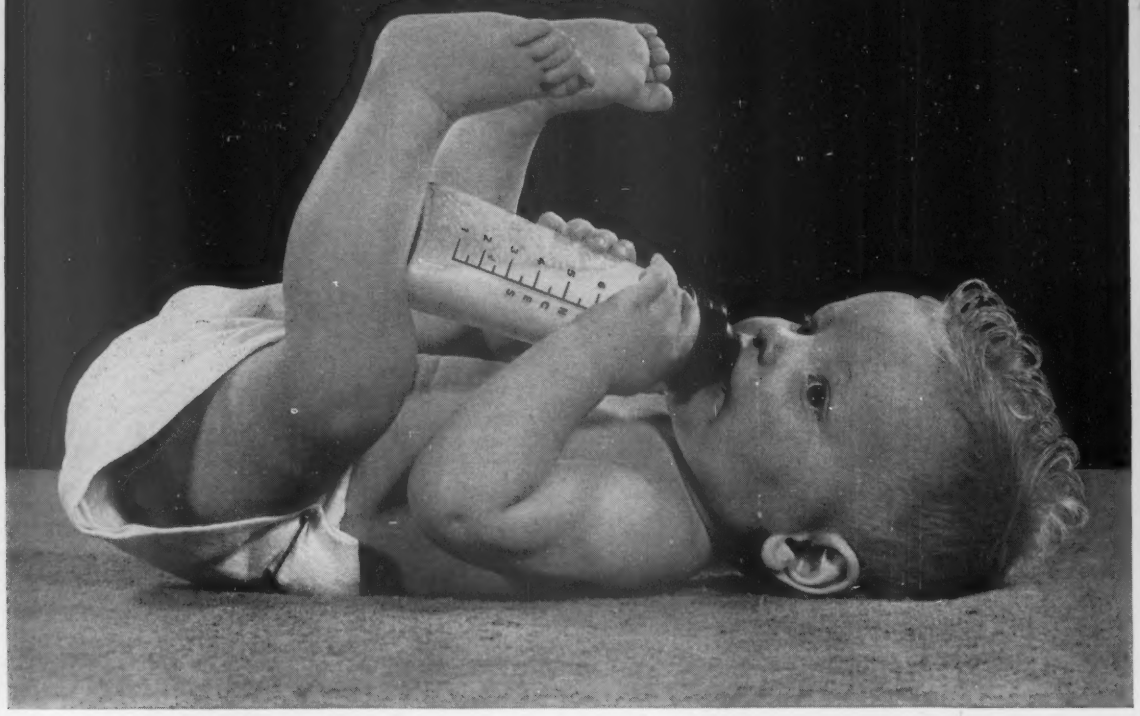
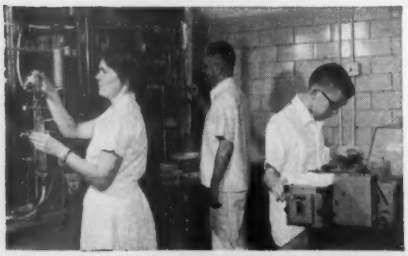


. . . that's when you can count on help from CES, the Castle Engineered Sterilization program. At your disposal are the results of a three-year study of the many packaging films, papers and laminations suitable for use with the Castle Sterox-O-Matic ethylene oxide process. Our analyses of factors such as gas and water absorption, ability to withstand pressure fluctuation, color retention and clarity in packaging may be a real help to you.

Right now we're doing research for some of the country's biggest producers of sterile-packaged products. By many we're recognized as the leading authority on sterile packaging. Be that as it may, we'd like to put our resources to work for you, too.



CES research leads the ever-widening search for better sterilizable packaging materials.

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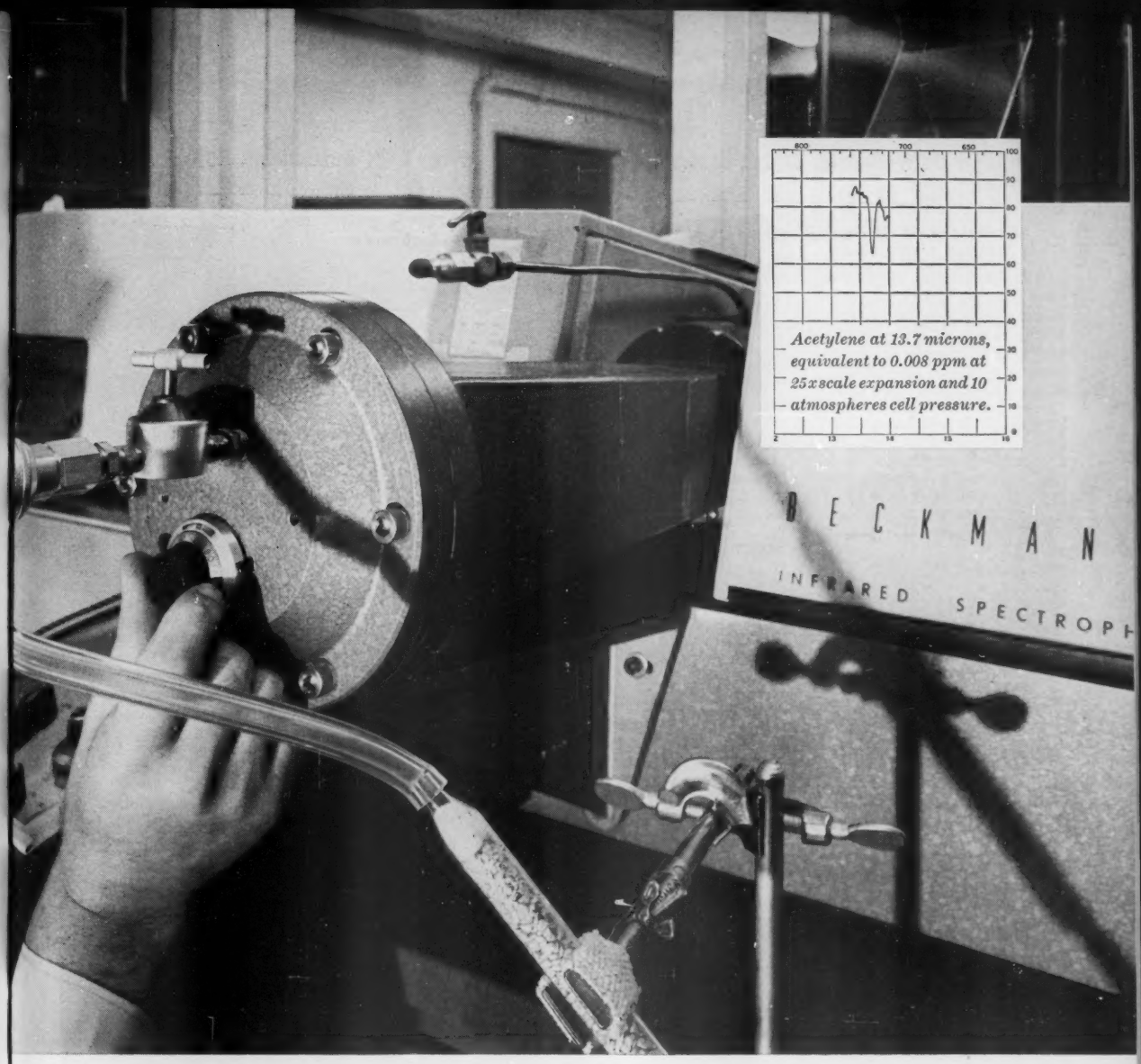
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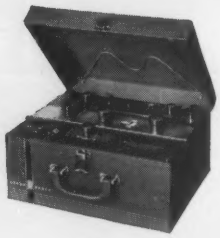
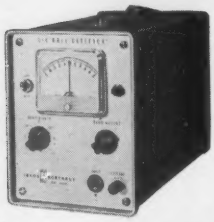


The use of this three-dial 8686 Portable Potentiometer is rapidly spreading in research laboratories. It features a central reading window . . . where measured values appear as a row of digits plus a scale value . . . for rapid reading of test results. This instrument has a wide operating range of −10.1 to +100.1 mv and an accuracy of ±(0.05% of reading +3μv) without reference junction compensation; ±(0.05% of reading +6μv) with ref. jct. comp. Write for Data Sheet E-33(1a).



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Used in research and testing applications as a null detector for guarded or unguarded potentiometers or bridges, this 9834 Detector has a period of less than two seconds for source resistance up to 1000 ohms, increasing to four seconds at 100,000 ohms. This portable, line-operated instrument has four degrees of sensitivity with a basic sensitivity of 0.2 μv/mm (0.3 μv/scale division) and a noise level of less than ±0.1 μv. Write for Data Sheet ED7(2).

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With L&N Automated Equipment

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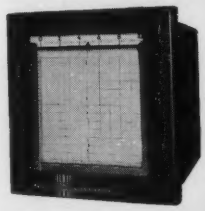

These compact, low-cost Speedomax® H Recorders are widely used in laboratories for measuring temperatures, millivolts, pH, gas chromatography, etc. With interchangeable ranges—50 for temperature and six for millivolt (0 to 1, 0 to 5, 0 to 10 mv, etc.)—these instruments will record practically any variables encountered in research work with a limit of error of ±0.3% of span. Write for Data Sheet ND46-51(100).

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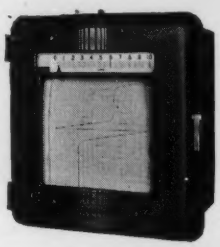
TO RECORD TEMPERATURES WITH AN ACCURACY OF ±0.01 C



Invaluable in advanced research laboratories, this High Precision Speedomax G Recorder is used with L&N Resistance Thermometers for a variety of temperature measurements over a range of −190 to +500 C with an accuracy of ±0.01 C. An "automatic Mueller Bridge," this recorder is used in cryoscopic determinations of purity, in measuring boiling ranges of liquids and in general calorimetry, etc. Write for Data Sheet E-ND46(7).

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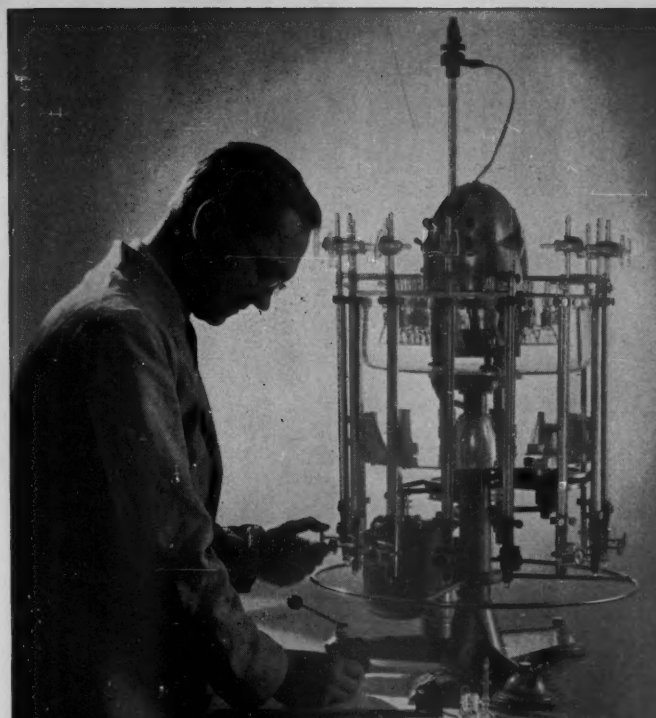

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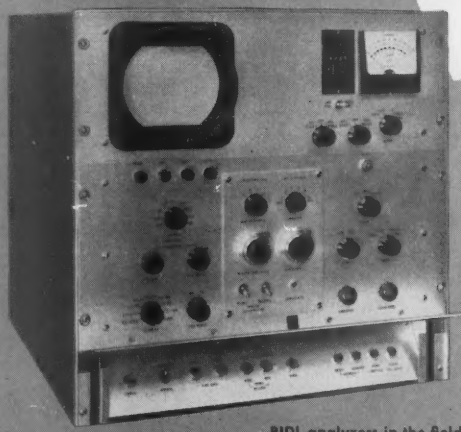
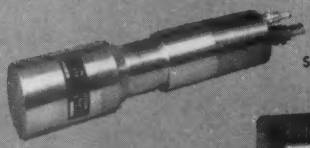
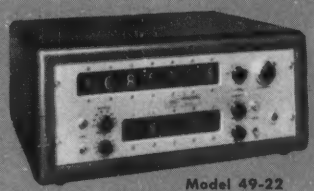


MODEL 34-8 200 Channel
MODEL 34-12 400 Channel

Transistorized Multi-Channel Pulse Height Analyzers

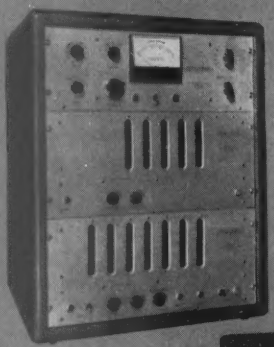


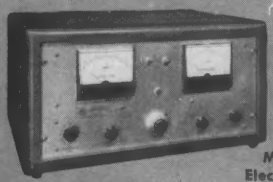
Model 10-2
Scintillation Detector



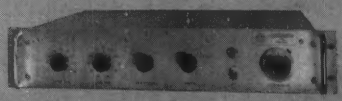
Model 49-22
Transistorized Scaler

RIDL analyzers in the field have now established the *Model 34-8* 200-channel and the *Model 34-12* 400-channel transistorized *Multi-Channel Analyzers* as the best radiation analyzers available. Full production of both models has quickly spread their use all over the world.



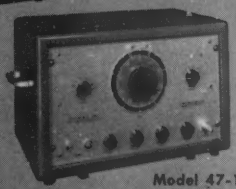


Model 39-1
Electronic Sweep



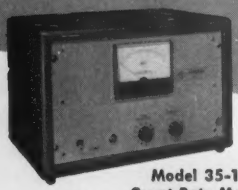
Model 30-16
Amplifier

Model 49-4
SCAMP Printing Scaler



Model 47-1
Pulse Generators

Model 50-1
Spectrometer



Model 35-1
Count Rate Meter

31 types of **scalers** . . . alpha, beta, gamma, x-ray, and neutron **detectors,** scintillation counters and **flow counters** . . . are available from RIDL . . . along with a full line of associated amplifiers and preamps. **Electronic sweeps** and all types of **spectrometers** are custom assembled from standard components. RIDL also manufactures a **pulse generator** for general nuclear laboratory use, **count rate meters** and a variety of **high voltage supplies.** The line of radiation instruments is made complete by several **single channel analyzers** and both two and four-channel **coincidence/anti-coincidence analyzers.**

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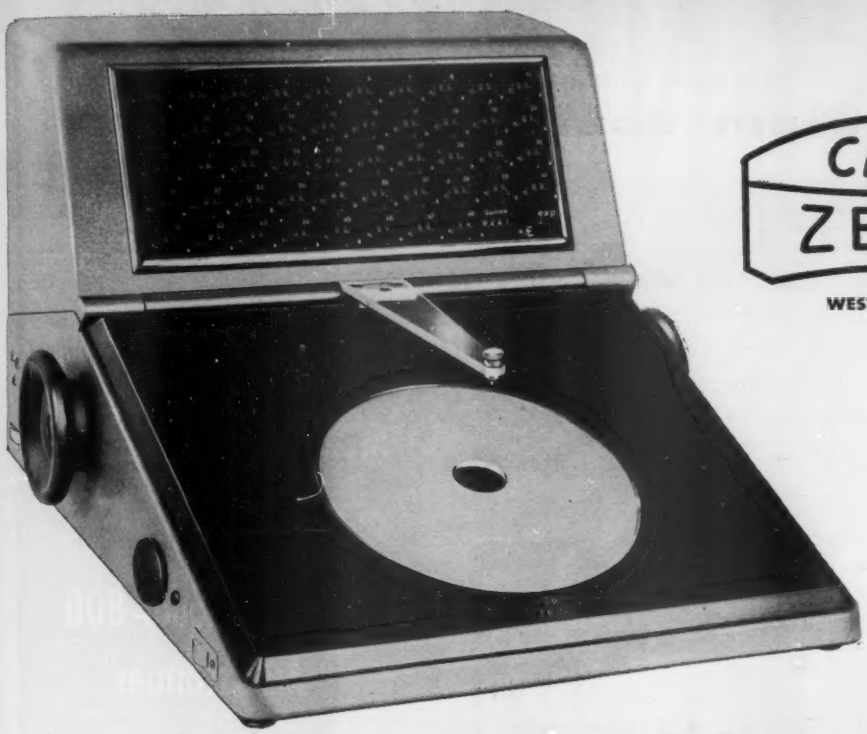

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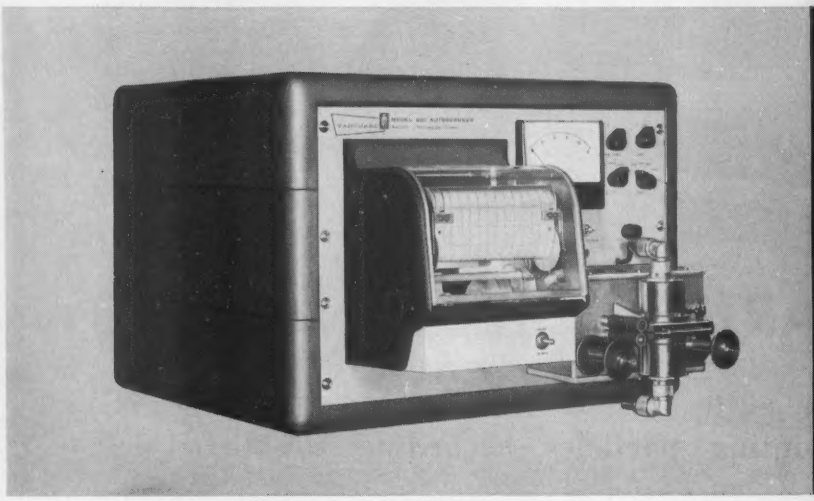

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Advanced features of the AUTOSCANNER include:

Completely automatic operation frees personnel for other duties. Power and gas flow are automatically shut-off after scanning period. When scanning connected multiple strips, individual strip length is monitored and permanently recorded on the chart paper.

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AUTOMATIC RECORDING TITRATOR

SCIENTIFIC INSTRUMENTS MODEL AT-2A

now — RECORD all potentiometric titrations AUTOMATICALLY!

New chart paper available for greater reading accuracy.

No longer is it necessary to expend valuable man-hours on tedious, point-by-point potentiometric titrations. Here is a single instrument that both performs and records variable and constant pH titrations — all automatically!

Speeds time-consuming measurements to free chemists for more productive efforts. And it's accurate to ±0.02 pH units or ±1.2 millivolts.

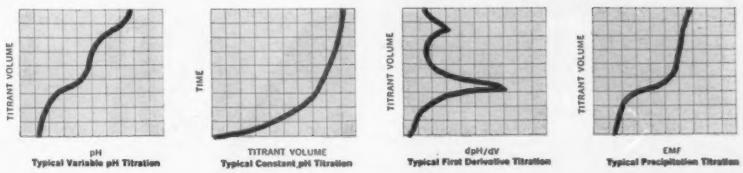
CAPABILITIES

* Automatic recording pH stat for reaction rate studies
* Records variation in pH or EMF as a function of titrant added
* Titrates to any pre-set end point
* Records first and second derivative titration curve
* Performs automatic titrations in aqueous or non-aqueous media: Acid-base reactions — Oxidation-reduction reactions — Precipitation reactions — Complex-ion reactions
* Automatic process control, lab or industry

FEATURES

* Internal calibrator to check titrator's response
* Titrant addition rate adjusts automatically as end-point approaches
* Variable titrant delivery rate and chart speed
* Automatic cutoff for unattended operation
* Interchangeable burets for micro and macro titrations
* With plug-in differentiator, pH or EMF is displayed on meter as recorder plots first or second derivative curve
* Adjustable recorder span; maximum sensitivity 2 pH or 120 mv full scale

records of typical functions — by model AT-2A



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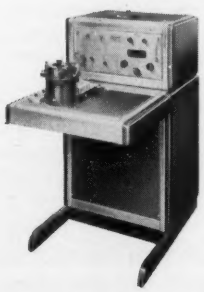
for true intrinsic viscosity measurements at extremely low shear rates...

SCIENTIFIC INSTRUMENTS MODEL RV-2



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* Rapid, simple changing of shear rates

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☐ **Model RV-2 Rotating Cylinder Viscometer**

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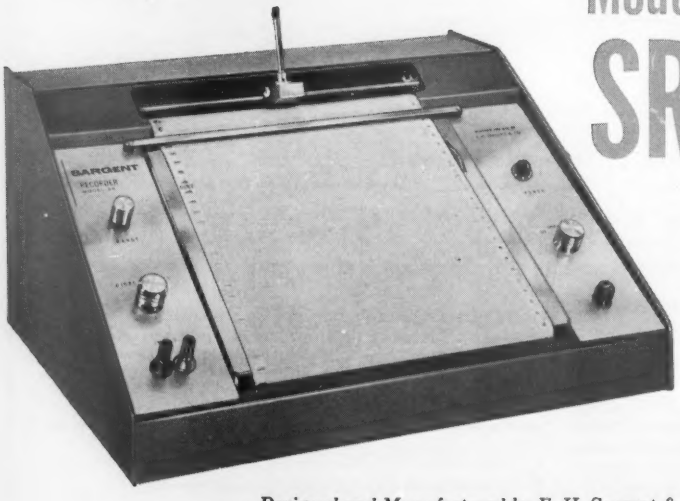
SARGENT

Laboratory Recorders

Model MR



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The Model "MR" features: 31 Potentiometric Ranges; 9 Chart Speeds, or 27 Chart Speeds with the Sargent Multi-range Attachment; and it is designed for laboratory bench operation.

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S-72151 Sargent Recorder
with Multi-Range Attachment, 27 Chart Speeds $1775.00

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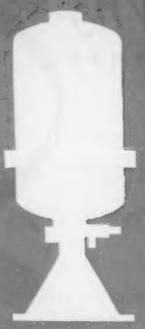

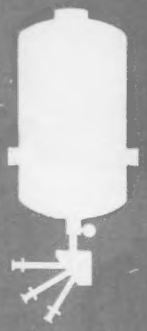

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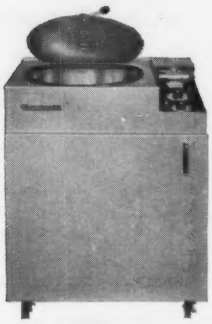

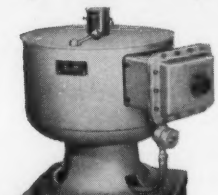

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For recording Titration Curves
For Use as a Recording pH Stat

SBR2
RECORDER

TTT-1
AUTOMATIC TITRATOR

SBU1
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UNIT

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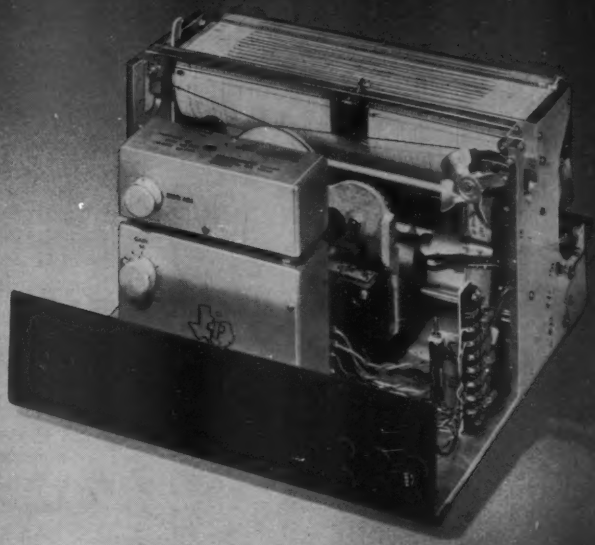

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The old cliché, "You can pay more but you can't buy better" was never more applicable than in the new "servo/riter" recorder. Texas Instruments has developed a self-balancing potentiometric recorder that incorporates *premium* engineering refinements, sensitivity, reliability and quality construction as *standard* equipment.

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Fast Pen Speed — Span step response is less than 0.5 second.

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There are four "servo/riter" recorder models to choose from . . . *Single Channel, Narrow Grid; Single Channel, Wide Grid; Dual Channel, Narrow Grids; and Dual Channel (overlapping pens), Wide Grid.* Write for technical literature and TI engineering assistance in your specific end or OEM use.

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The new "servo/riter" recorder is a companion to the proved "recti/riter" recorder.

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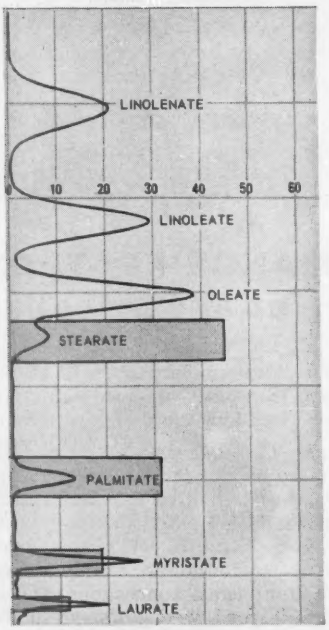

Typical gas chromatogram trace showing mass peaks of fatty acid methyl esters. Superimposed on the mass trace, the bar graph indicates no radioactivity in any of the unsaturates.

The Packard Model 830 Tri-Carb® Gas Fraction Collector enables quantitative collection of individual organic components in a gas chromatographic effluent stream. Precise measurement of radioactivity in component peaks can be made after collection.

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After sample collection, the cartridges are placed in positioning adapters in an Automatic Tri-Carb Liquid Scintillation Spectrometer for completely automatic counting. No sample preparation is necessary and up to 100 samples can be handled at one time.

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The Packard Model 830 Tri-Carb Collector is suitable for use with any gas chromatograph using a nondestructive mass detection system.

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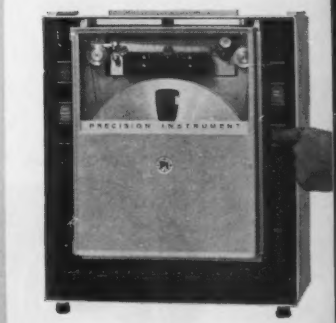
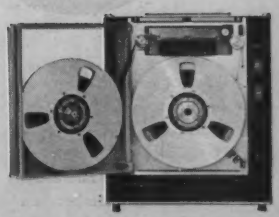
TWICE the frequency response previously obtainable with conventional recorders

TWICE the recording time for a given length of tape—as much data on a 10½ inch reel as previously on a 14 inch reel

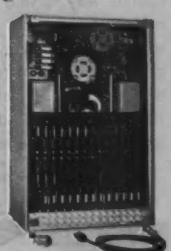
TWICE the economy. HIGHER reliability, LOWER flutter, LESS maintenance

Write for your copy of Bulletin 59, which describes the new Precision π Recorder, based on the thoroughly tested and field-proven design of the FIRST all-solid-state instrumentation tape recorder, the Precision PS-200 Series.





Open door view of 7-channel machine, showing loaded tape magazine which can be interchanged in 5 seconds.



Rear view of 14-channel recorder which weighs only 105 pounds, fits in only 26½ inches of rack space.

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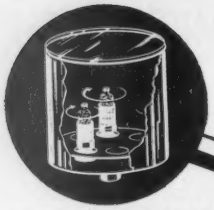

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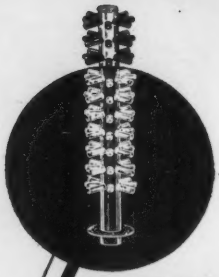
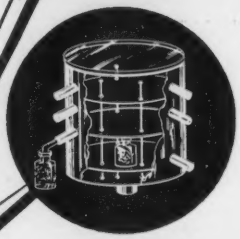


CULTURE DRYING



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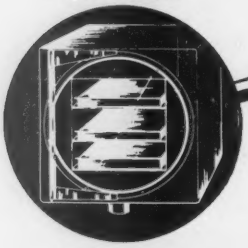

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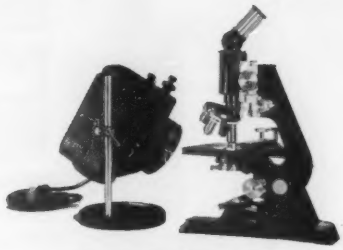

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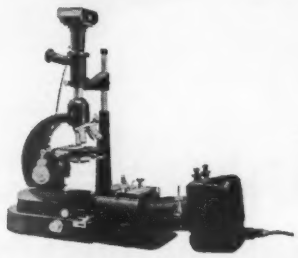

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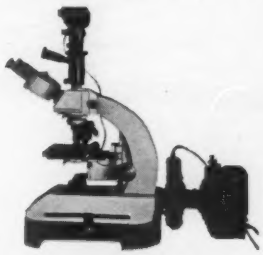

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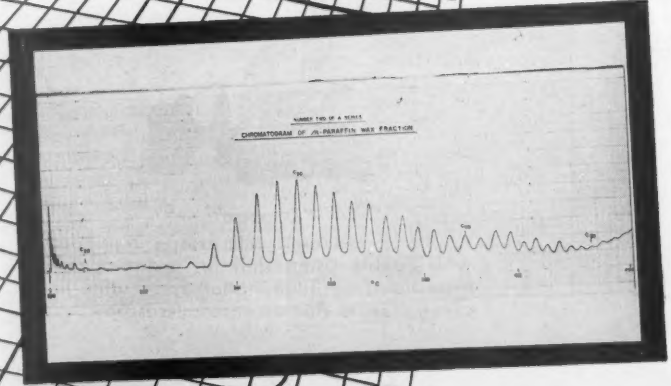

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LITERATURE CITED

(1). *Anon, *"Gas Chromatograph Hits High °C.," Chem. and Eng. News, 38,* 42-43 (1960).
(2). Dal Nogare, S., and Safranski, L. W., *Anal. Chem., 30,* 894-898 (1958).
(3). *Martin, A. J., Bennett, C. E., and Martinez, F. W. Jr., *"Linear Programmed Temperature Gas Chromatography to 500°C.,"* presented at the Cleveland ACS Meeting, April 1960.
(4). Ogilvie, James L., Simmons, M. C., and Hinds, G. P. Jr., *Anal. Chem., 30,* 25-27 (1958).
(5). Scott, C. G., and Rowell, D. A., *Nature, 187,* No. 4732, 143-144 (1960).

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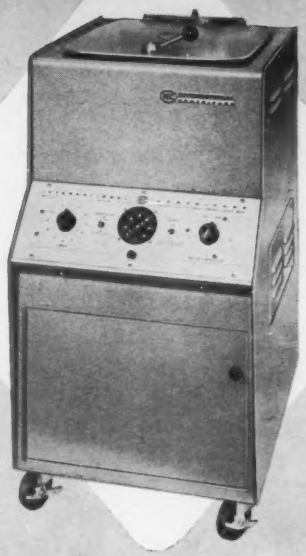

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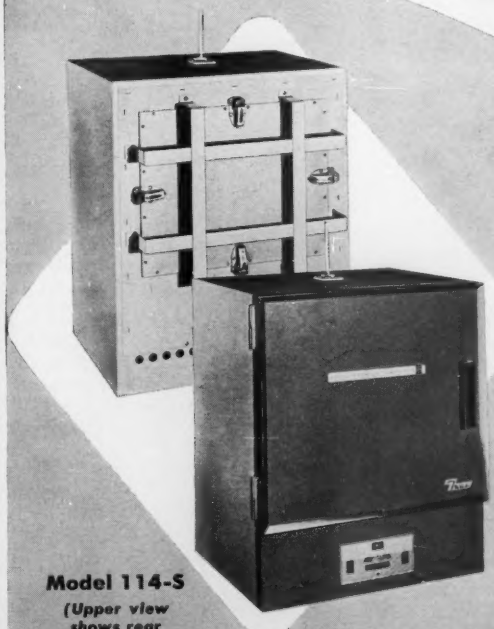

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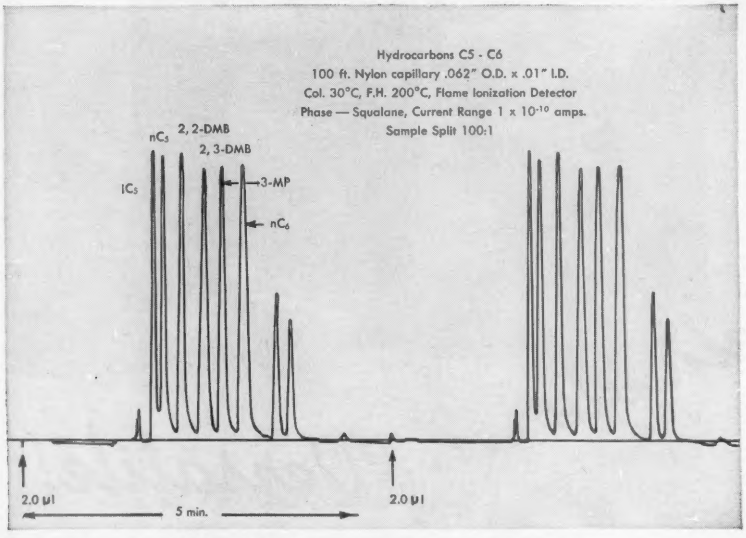

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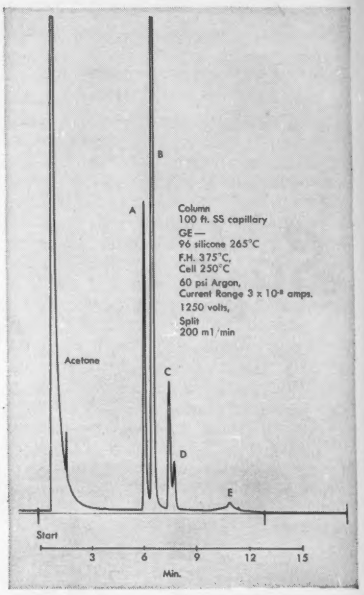

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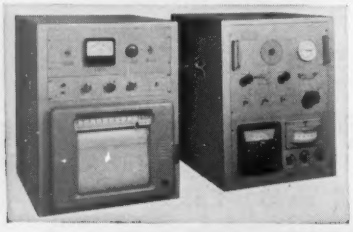

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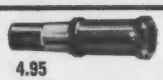

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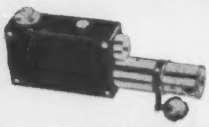

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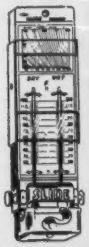

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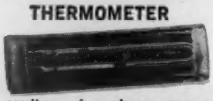

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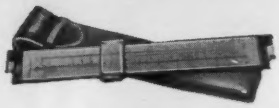

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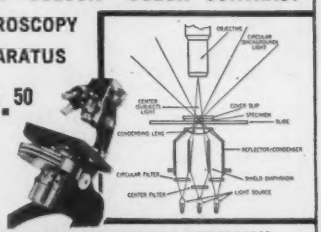

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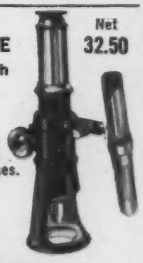

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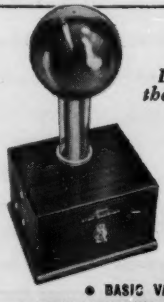

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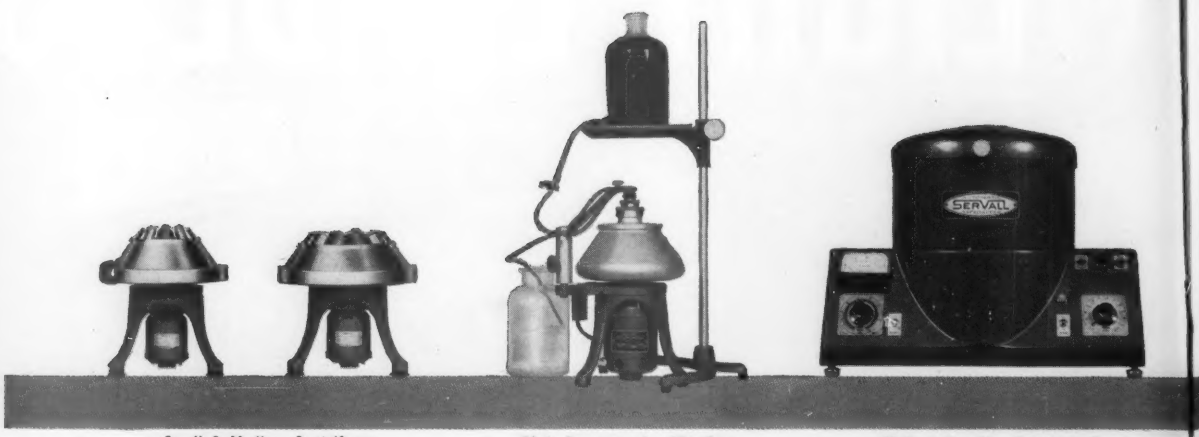

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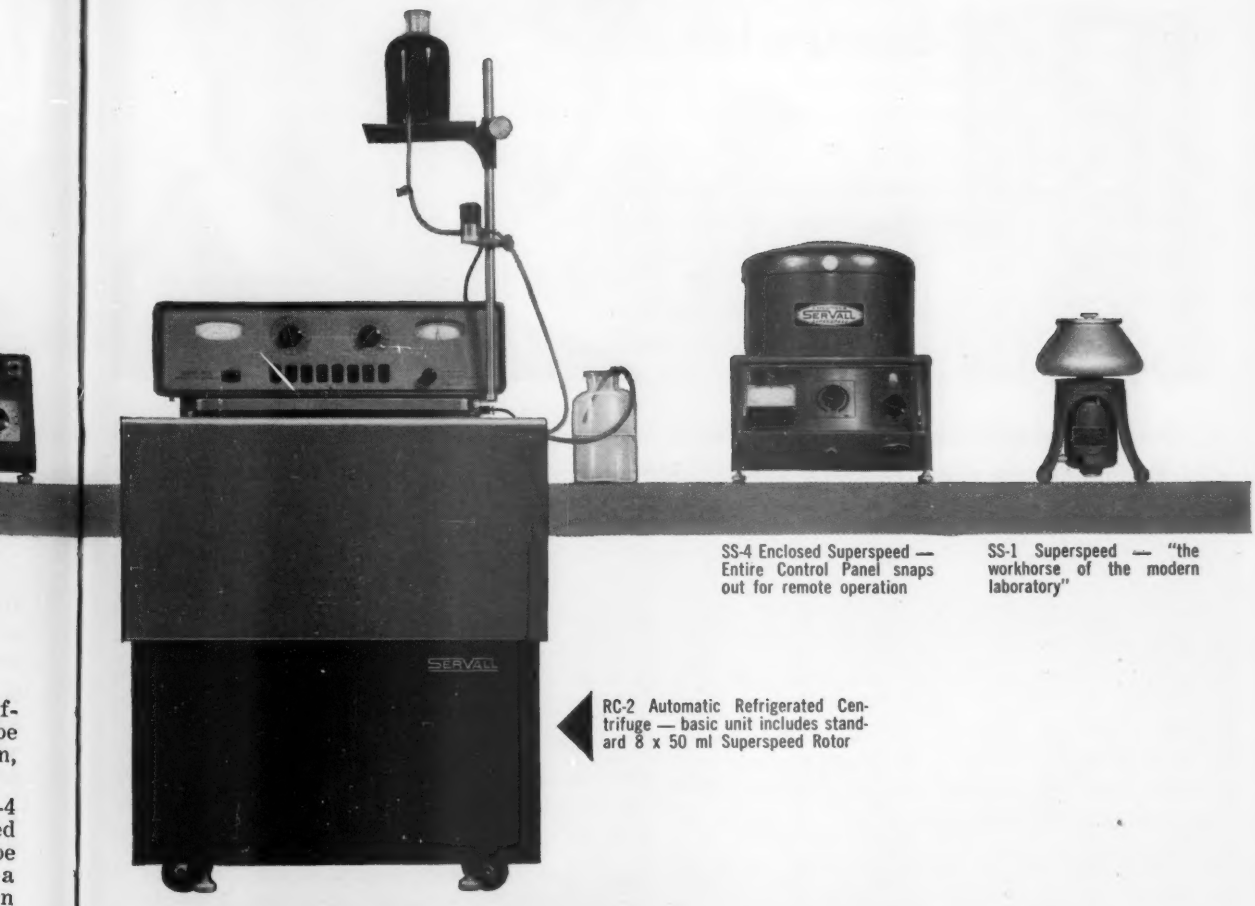

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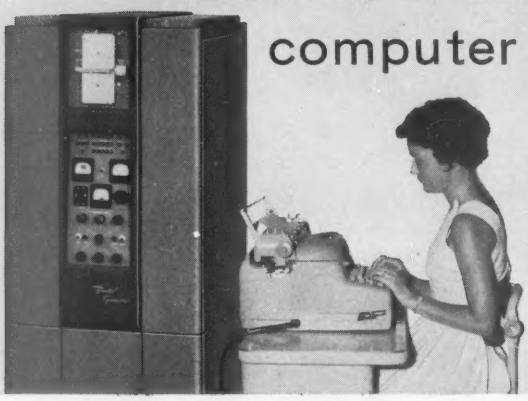

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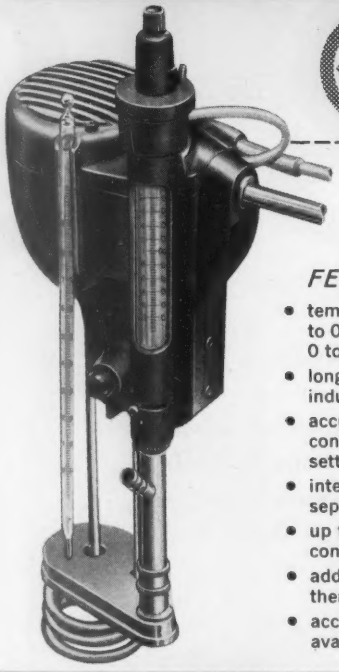

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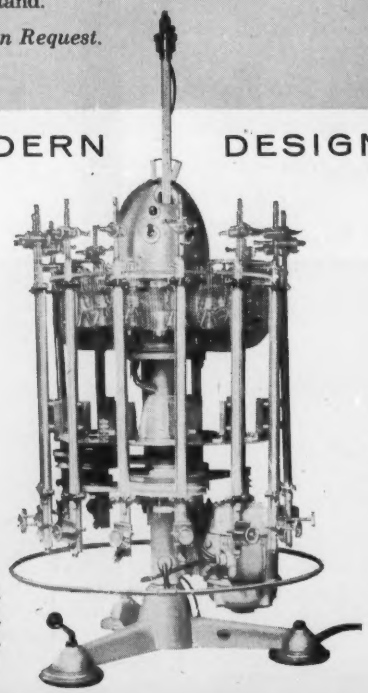

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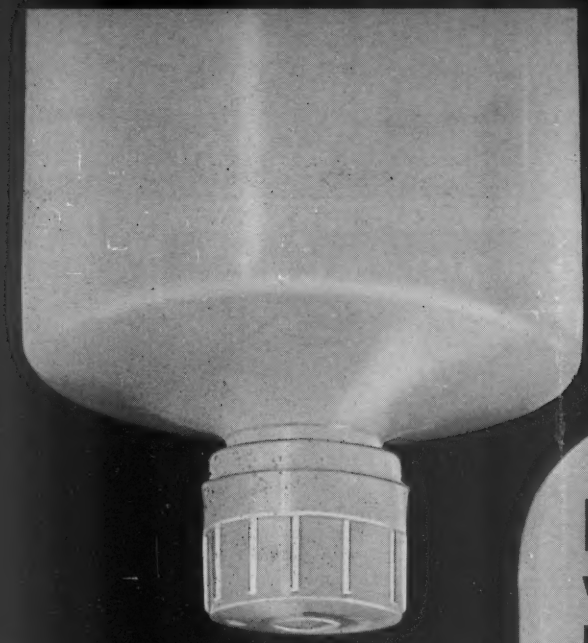

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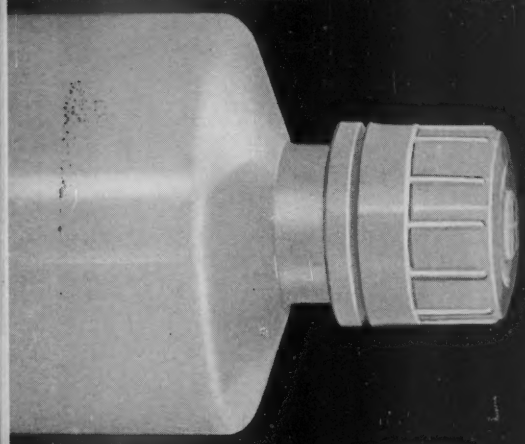

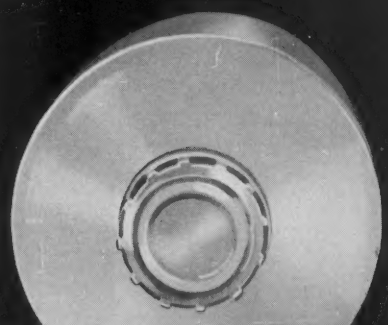

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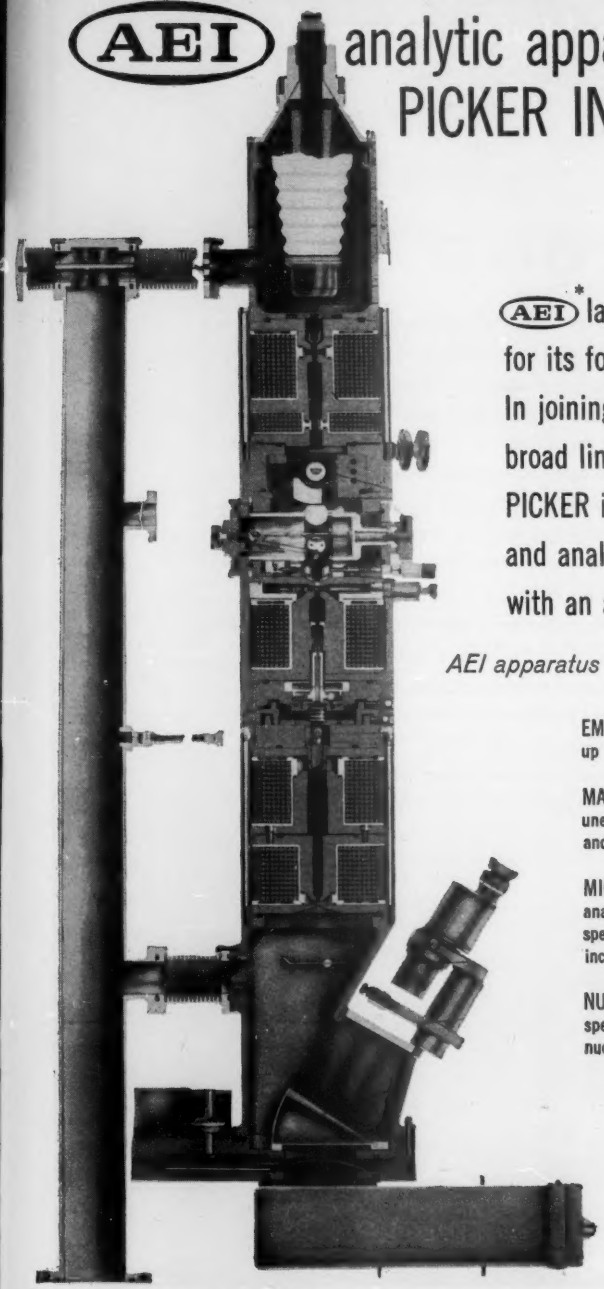

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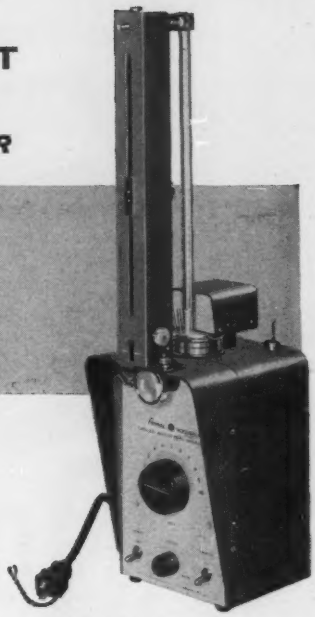

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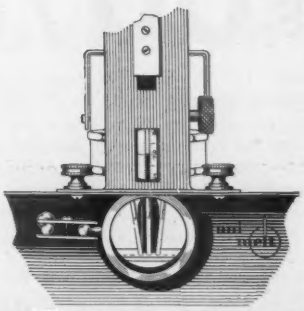

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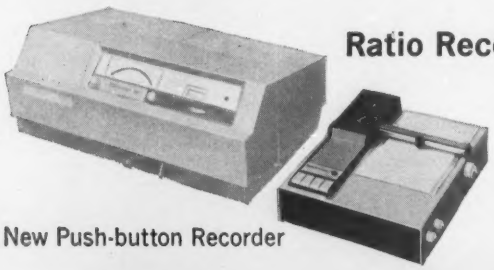

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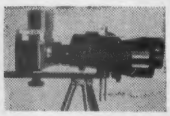

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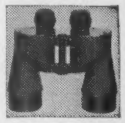

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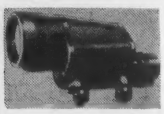

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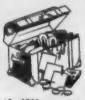

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One glance at the vast array of ratemeters on the market today and you can readily realize the growing importance of these instruments for use in radioisotope laboratories and clinics. To help select the one best ratemeter for you from this bewildering variety of models, a simple seven-point check list has been developed. Before making a decision, consider these points carefully:

1. Range and Number of Scales
2. Range and Number of Time Constants
3. Stability and Range of the High Voltage Supply
4. Stability of Calibration
5. Low Zero Drift
6. Functional Design
7. Cost

When you examine the Tracerlab line, we believe you will find that for versatility, quality, ease of operation, precision and real value, you simply can't beat Tracerlab Ratemeters.

For example, Tracerlab's standard laboratory ratemeters offer a choice of nine full-scale ranges from 0-100 c.p.m. all the way up to 0-1,000,000 c.p.m. with intermediate ranges in multiples of 3 and 10. This extremely wide choice of ranges provides the versatility you require in selecting the optimum range for any given application.

Number and range of time constants is important, too (Tracerlab's standard laboratory ratemeter has eight). Very short time constants on the upper range scales permit rapid response with no significant increase in probable error while longer time constants on the lower ranges will damp out most of the statistical fluctuations common to these count rates. On the higher ranges a minimum time constant of 0.05 seconds is provided, while for low count rates, a 40 seconds time constant is available. Tracerlab Ratemeters have stability of calibration and zero drift is virtually eliminated.

The ratemeter you select should have a precision high voltage power supply with a high degree of regulation to insure negligible output voltage changes when input voltage varies. The power supply output voltage of Tracerlab Ratemeters changes less than 0.003% for a 1% change in input voltage. As a result, they can be used with scintillation as well as geiger detectors. What's more, you don't need to buy an additional power supply when you use a Tracerlab Ratemeter with a Spectrometer. Why? Because standard equipment on all Tracerlab Spectrometers includes a super regulator that provides all the additional stability your Tracerlab Ratemeter power supply needs for precision spectrometry.

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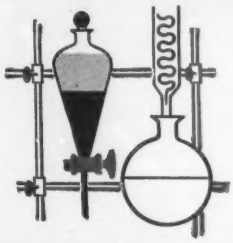

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Propionic Acid (R)

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Alcohol, Specially Denatured (R)
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n-Amyl Alcohol (R)
tert-Amyl Alcohol (R, P)
iso-Butyl Alcohol (R, P)
n-Butyl Alcohol (R)
tert-Butyl Alcohol (R)
Cresol (USP)
Cyclohexanol (R)
Ethylene Glycol (R, P)
Glycerol (R, USP)
n-Hexanol (R)
Methanol (R, P)
2-Octanol (P)
Phenol, Liquified (USP)
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Acetone (R, NF)
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Chloroform (R, USP, T)
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Ethyl Iodide (R)
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Ethylene Dichloride (P)
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Methylene Chloride (R)
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Methylcyclohexane (P)
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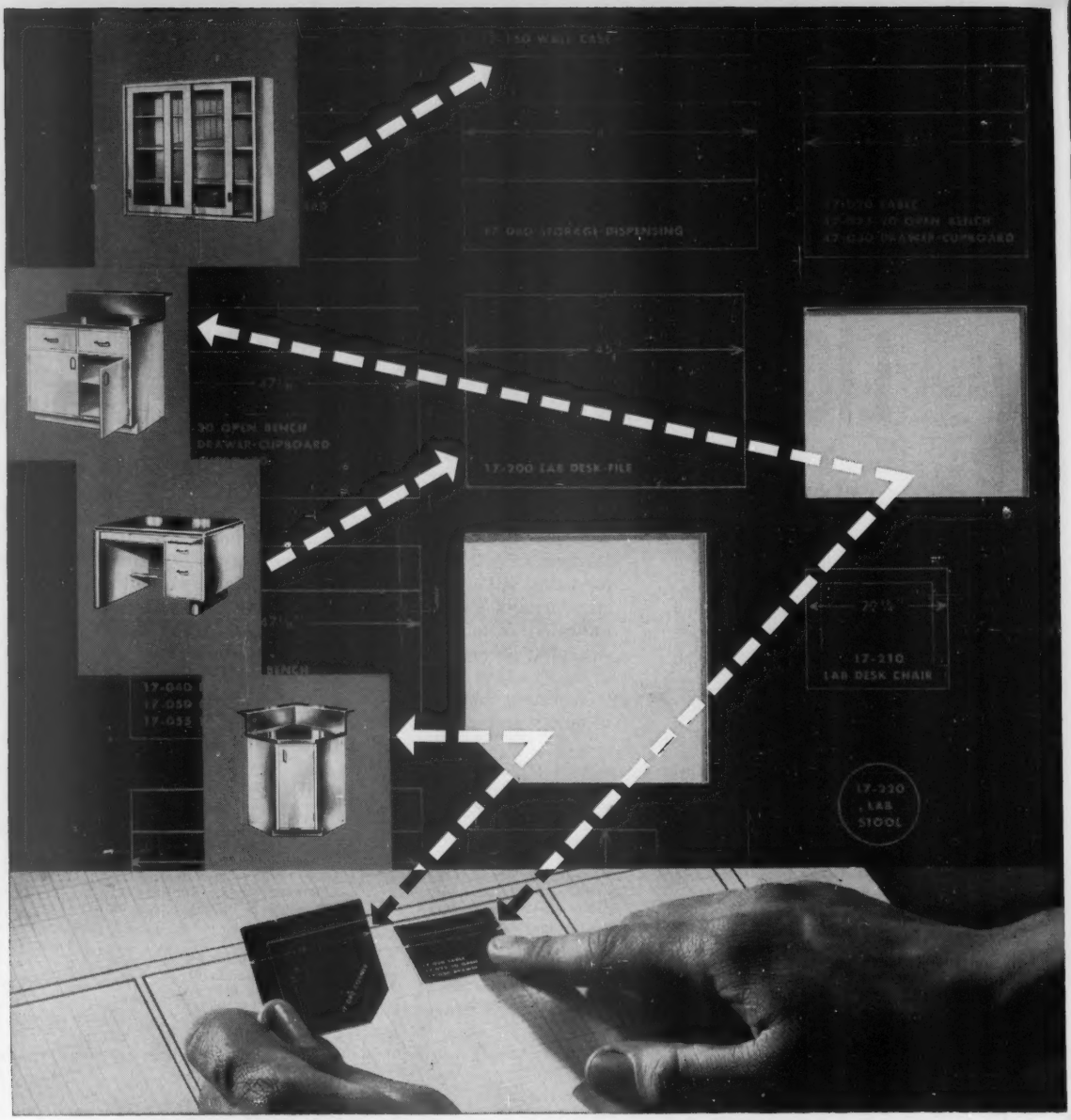

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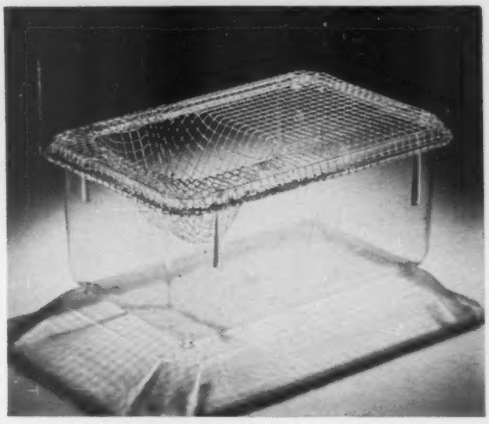

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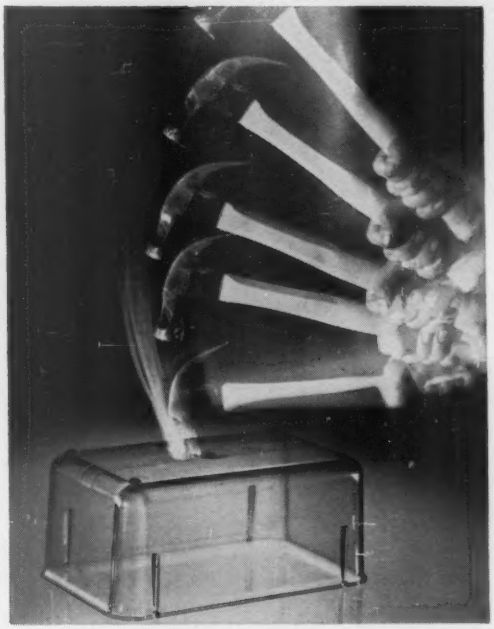

The Cage

The overall dimensions of Econo-Cage #27 are 11½″ by 7½″ by 5″ deep. It is one of "#20 series" Econo-Cages designed primarily for mice. The cage uses lids #22A, #22B, #22C, and #22D.

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Difficult Decisions

If you can't do everything you want to do, how do you decide what to do? For an individual, such decisions are comparatively easy —a washing machine instead of a Deepfreeze or both in some order of priority: a washing machine this year, a Deepfreeze next year. For the individual scientist a similar system of choice must prevail; he gives one experiment priority over another.

The decisions become more difficult to make in assigning experiments for large and expensive equipment. More people want to schedule experiments for a big synchrotron or a nuclear pile than time permits. Who is to decide how to allocate experiments? One solution would be to build enough synchrotrons and nuclear piles so that all worthy projects could be carried out promptly. But decisions of this kind have to be made at the national level. Shall we build this additional equipment or an oceanographic vessel? Or a radiotelescope?

Perhaps no scientific activity poses these questions in clearer form than does the exploration of space. The lead time for planning experiments and the vehicles to launch them is several years. The equipment is expensive, and it can be used only for one group of experiments. It is as though an oceanographic vessel would be able to set up only one buoy equipped with numerous instruments and would then explode: one ship, one set of experiments.

The decisions in this field have had to be made by the National Aeronautics and Space Administration (NASA). No perfect mechanism for decision making exists, but NASA has worked in close liaison with the National Academy of Sciences—National Research Council's Space Science Board and the President's Science Advisory Committee, as well as with panels of scientists from outside the government.

One of the major decisions that had to be made early was whether or not to launch a crash program to overtake Russia in the brute force competition in spatial weight lifting. NASA decided instead to develop a well-balanced scientific program and has recently laid out a ten-year schedule to accomplish its aims, which will include the development of high-thrust vehicles.

Although most of the projects seem to most scientists to be in good balance, one in particular is criticized. This is the Mercury or man-in-orbit project, which has been given a top priority. The argument against this undertaking is that the yield of scientific information from a man in low orbit will probably be less than that attainable by substituting for a man and his supplies an equivalent weight of instruments. Here is a prime example of a difficult decision. Granted that the immediate scientific results of launching a manned satellite will not be as great as those obtainable by other means, is this the overriding consideration? The NASA decision can be defended on two grounds. Sooner or later man is going to go deep into space—say, to the moon or Mars—where he can contribute much to the scientific results, and exploratory flights over short periods of time are essential first steps. Furthermore, the United States does not exist in a political vacuum; it cannot afford to lag far behind the Soviet Union in getting a man into orbit.

That all decisions made in so vast an enterprise as the exploration and exploitation of space will satisfy everyone is obviously too much to hope for. That in the first two years of its existence NASA has done as well as it has in balancing all factors—political, psychological and scientific—is ground for congratulations.—G.DuS.

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CURRENT PROBLEMS IN RESEARCH

New Developments in Hail Research

Artificial production of hailstones leads to advances in the understanding of their natural formation.

Roland List

Men have long been curious about the natural phenomenon of hail, and it is therefore not surprising to find that hailstones have become the object of intensive study among scientists during the last century (*1*). What is astonishing is, rather, the variety of observational material collected and the conclusions derived from it. As a result of wars on the continent of Europe, however, a large part of this knowledge has been lost, and although leading centers of research have been built up in England and the United States, their traditions do not go back so far. A perusal of the scant statements about hail formation in the standard work *The Physics of Clouds* (*2*) makes this situation quite clear.

Where observational material was lacking there was all the more imaginative speculation about the way in which hail is formed. The first major hail theory in mathematical form was given by Schumann in 1938 (*3*). Although it has not been borne out in every detail, it contains most of the assumptions necessary for a procedure of this kind. Subsequent work has pointed out very little that is new in this respect. On the contrary, further development has tended to be trivial, degenerating into mere exercises in calculation based on apparently reasonable assumptions. The effects and countereffects that have been calculated have led to a series of propositions and counterpropositions, all of them the work of the same researchers, who can continually invoke them to demonstrate the correctness of this or that point of view.

It is consoling that nature has allowed unforeseen and surprising discoveries to be made, which result in the more or less complete collapse of these proud intellectual constructions.

Research Methods of the Hail Research Station in Davos

It was, in fact, dissatisfaction with the whole development of hail research that led to a fundamentally new approach to all the problems on an experimental, physical basis. Existing publications were duly taken note of but not used as a foundation—a procedure which turned out to be fully justified.

The aim of research at Weissfluhjoch is to clarify understanding of the atmospheric conditions that lead to the formation and growth of hailstones. There can be no question, because of the extraordinary risks involved, of measuring by airplane the unknown parameters in an actual storm cloud with hail: the air temperature, the air pressure, the free-water content in the form of drops, the magnitude spectrum and supercooling of the particles, the icing nuclei spectrum, the speed of upcurrents, and the speed of hailstones relative to their environment. Therefore, other methods have had to be sought.

To design sounding devices that will penetrate hail clouds presents equal difficulties, and there is no guarantee that these devices will rise through the most dangerous cloud zones. But of the conditions that prevail there, we do in fact have evidence: the hailstones themselves represent nothing less than the product of these conditions, and the largest hailstones bear witness to the strongest icing conditions.

This means that it is useful to investigate the structure and build-up of natural hailstones. What has been learned from such an investigation is presented in the next section. But when we look at the results, we see that we lack both the experience and the intuition to interpret the various signs and symptoms. We need still to make such experiments as will give us the knowledge upon which to base our interpretation. The apparatus that achieves an imitation of the icing process under atmospheric or even more extreme conditions is the Swiss hail tunnel. On the one hand, experiments that can be conducted in this wind tunnel with variable climate give us information about the relation between atmospheric conditions and the resultant ice deposit, and thus also provide the foundations for a modern, physical hail theory based not merely on reasonable but on correct assumptions. The significance of this is discussed in subsequent sections. On the other hand, these experiments offer the key to an interpretation of the way in which actual, collected hailstones have been built up. From the data ob-

The author is head of the hail section at the Swiss Federal Snow and Avalanche Research Institute, Weissfluhjoch-Davos, Switzerland.

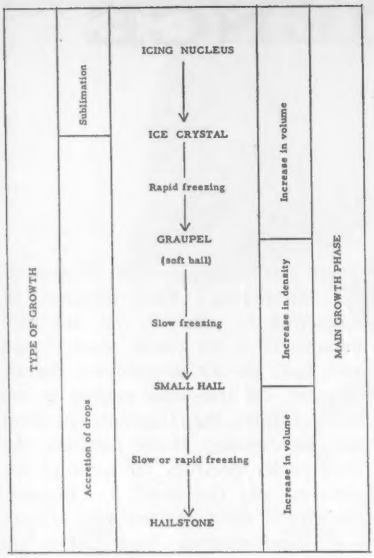


Fig. 1. Characteristics of the growth of hailstones.

tained by this method it should be possible to extrapolate from the physical space surrounding individual ice particles to meteorological space. However, we have deliberately limited ourselves to the physical space of hail formation, for an understanding of the processes here is essential for a meteorological hail theory that is also physically correct and that takes account of the processes in nature.

Origin and Build-up of Hailstones

The location of the research institute at 2665 meters above sea level affords a unique opportunity for direct observation of all phases in the formation of hail and for investigation of the ice particles peculiar to each phase. Of particular interest are those cases where two or more stages in the formation of hailstones and of the particles from which they originate can be observed together. The results of all these observations are given in Fig. 1 and show the development from an ice-forming nucleus into an ice crystal, then into a soft hail particle, then into "small hail," and finally into a hailstone. There is an important difference to be noted between an increase in volume and an increase in density without increase in volume. This means that two growth phases can be spatially superimposed, so that the open ice framework of a graupel (soft hail particle) can be filled up at a later point in time with slowly freezing water, which may even remain partly liquid. This produces a small hail particle, about which more specific details are given below. Subsequent interpretation of hailstone structures is, of course, complicated by this filling up of loose ice zones. There are, however, certain unmistakable signs which in many cases permit clear identification of two such superimposed growth phases.

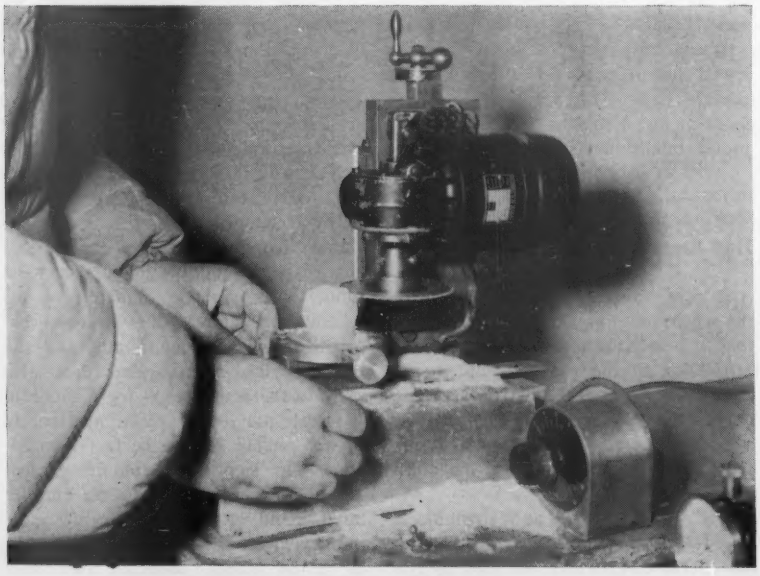


Fig. 2. Thin section saw.

At this point it should also be remarked that various research workers are of the opinion that the formation of hailstones starts from drops of water. Indeed, there are sometimes in individual hailstones indications to support this point of view. In the majority of hailstones, however, graupels can quite clearly be recognized as the originating particles, and they can contain an ice crystal which in 50 percent of all cases can be identified—a crystal of dendritic form (*4*). There is no reason, therefore, to modify the scheme shown in Fig. 1.

Characteristics of Hailstones

Published works often give drawings and photographs of hailstones together with sizes, and sometimes also details about weight. But we find that figures are wanting as soon as we inquire about density. The earliest more or less reliable values for density were those obtained by me (*5*), while measurements were also made later by Vittori (*6*). These measurements, however, were not made on freshly fallen hailstones but on hailstones that had been kept before and during measurement at a temperature below 0°C. This fact is of decisive importance, as was established only later (*7*), because the hailstones *normally* contain liquid water and thus exhibit a density greater than that of ice.

It is also important to indicate and classify the *forms* of hailstones, since their form is responsible, in the first place, for their aerodynamic behavior when falling and, in the second place, should permit conclusions to be drawn retrospectively about the conditions in which they originated. For it can in fact be clearly shown that the form of a hailstone represents a consequence of these conditions (*8*). But as different growth phases can succeed one another in the development of these ice particles, it is necessary to learn all the different forms through which a hailstone passes during its growth. For this purpose mere external observation of the hailstone is no longer adequate; cross sections must be prepared in order to gain a picture of the inner structure.

Here the methods devised by M. de Quervain (*9*) for research on snow proved to be invaluable. By means of a special circular saw (Fig. 2), ice sections 0.2 millimeter or more thick

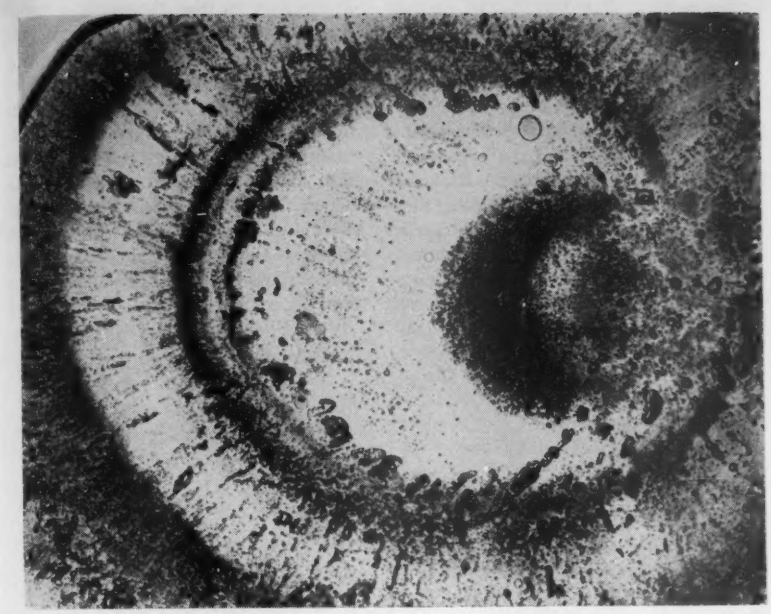


Fig. 3. Thin section of hailstone No. K 57.15, with translucent light (real length of the figure, 3.1 cm).

are cut out of the hailstones. A variety of such thin sections can be prepared from any given hailstone. When light penetrates these sections, the arrangement of the air pockets becomes visible, and from these the form at different stages of growth may be inferred wherever the air bubbles are arranged in onionskin-like layers. From the symmetry of the sections it is also possible to recognize the oldest part of the hailstone (see Fig. 3). Similar results are obtained from observing the crystal structure of the ice; for this, polarized light has to be used. Figure 4 shows one such arrangement of individual ice crystals. Figures 3 and 4 both show the same thin section. Further details about hailstone structures can be found in the references at the end of this article (*4*, *5*, *10*, *11*).

Aerodynamics of Hailstones

In every hail theory, assumptions must be made about the relative speed of hailstones in relation to their immediate environment. The obvious step was, of course, to idealize hailstones as spheres and to use the values obtained in the field of aerodynamics. Some 25 years elapsed, nevertheless, before such data were used to calculate the speeds of fall of spherical ice particles. Bilham and Relf (*12*) then repeated the experiments on the coefficients of air resistance for spheres, because the existing experimental data seemed to them to be too strongly affected by the turbulence in the wind tunnels that had been employed. Did they believe, perhaps, that in a storm cloud with hail, particularly laminary conditions would prevail? Despite a wide variety of contradictions, the calculations established by their work—calculations regarding the dependence of the speed of fall on the air density and the transition from laminary to turbulent flow resistance at the critical Reynolds number—were all adopted without exception. It is understandable that Schumann (*3*) should have based his work on these calculations, since in 1938 the knowledge gained from boundary-layer theory was still neither far developed nor well known: but it is surely surprising that modern work should still rely without hesitation on these results.

The great fallacy was to have idealized hailstones as smooth spheres and then to have attributed to them the flow characteristics of such spheres. This procedure is not permissible since hailstones can be idealized as at best *rough* spheres. Flow is then turbulent at a much lower Reynolds number, and higher coefficients of air resistance result (also different heat-exchange values). Above all, calculations concerning the "aerodynamically conditioned" maximal diameter of hailstones are invalidated, since these are based on the shift in the separation point of the air stream along the sphere at the critical Reynolds number.

But even with small ice particles we are dealing with the supracritical zone.

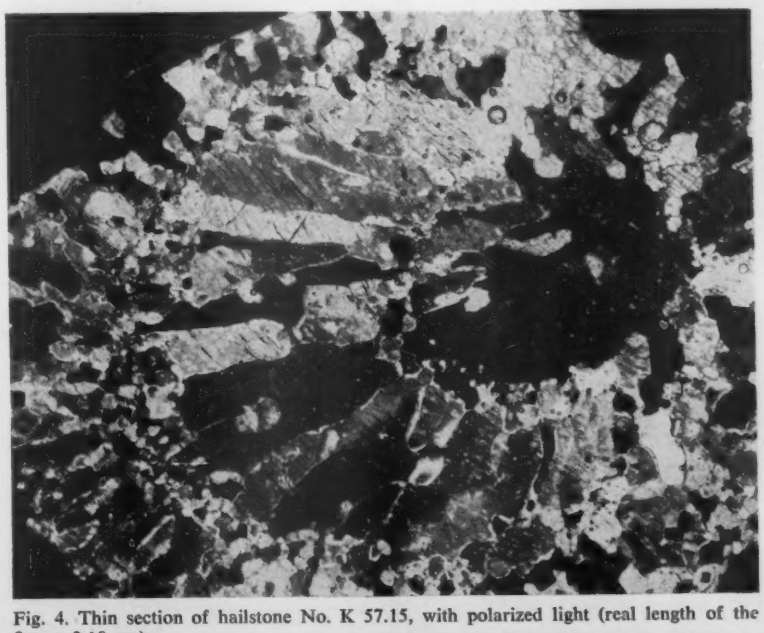


Fig. 4. Thin section of hailstone No. K 57.15, with polarized light (real length of the figure, 3.10 cm).

For this reason, therefore, it is necessary to measure the coefficient of air resistance on natural hailstones. The main forms in particular—for example, triaxial ellipsoids compressed along the shortest axis—have been measured. Figure 5 indicates the values obtained for hailstone No. K57.24 (weight, 24.3 grams; specific weight, 0.908 gram per cubic centimeter; ratio of main axes, 1.0: 0.79: 0.44). It may be mentioned here that a system of axes was in each case drawn through the hailstones, such that axis l_1 coincided with the largest diameter and axis l_3, with the smallest diameter of the ice particle. Measurements were made only of lines lying in the main planes. Fig. 5 shows the coefficients of air resistance C_w (where $W = C_w \cdot \delta \cdot v^2 \cdot F/2$), the projection plane of the hailstone against the air current F, and the appropriate speed of fall v thus obtained. Since not every direction of fall is stable, however, further experiments were carried out in a water tank, and these showed that these types of hailstone fall parallel with the smallest axis. If we represent the coefficients of resistance as a function of the Reynolds number, then we obtain zones of the kind indicated in Fig. 6. Unfortunately, the wind tunnel being used was not adequate for obtaining higher values of Re, so the figures are exact (that is, experimentally substantiated) only for hailstones with a maximum diameter of 6 centimeters. On the basis of Fig. 6, if we use values for C_w corresponding to the hailstone form, we obtain data for the speed of fall as shown in Fig. 7. As a basis of comparison the curve (No. 1)

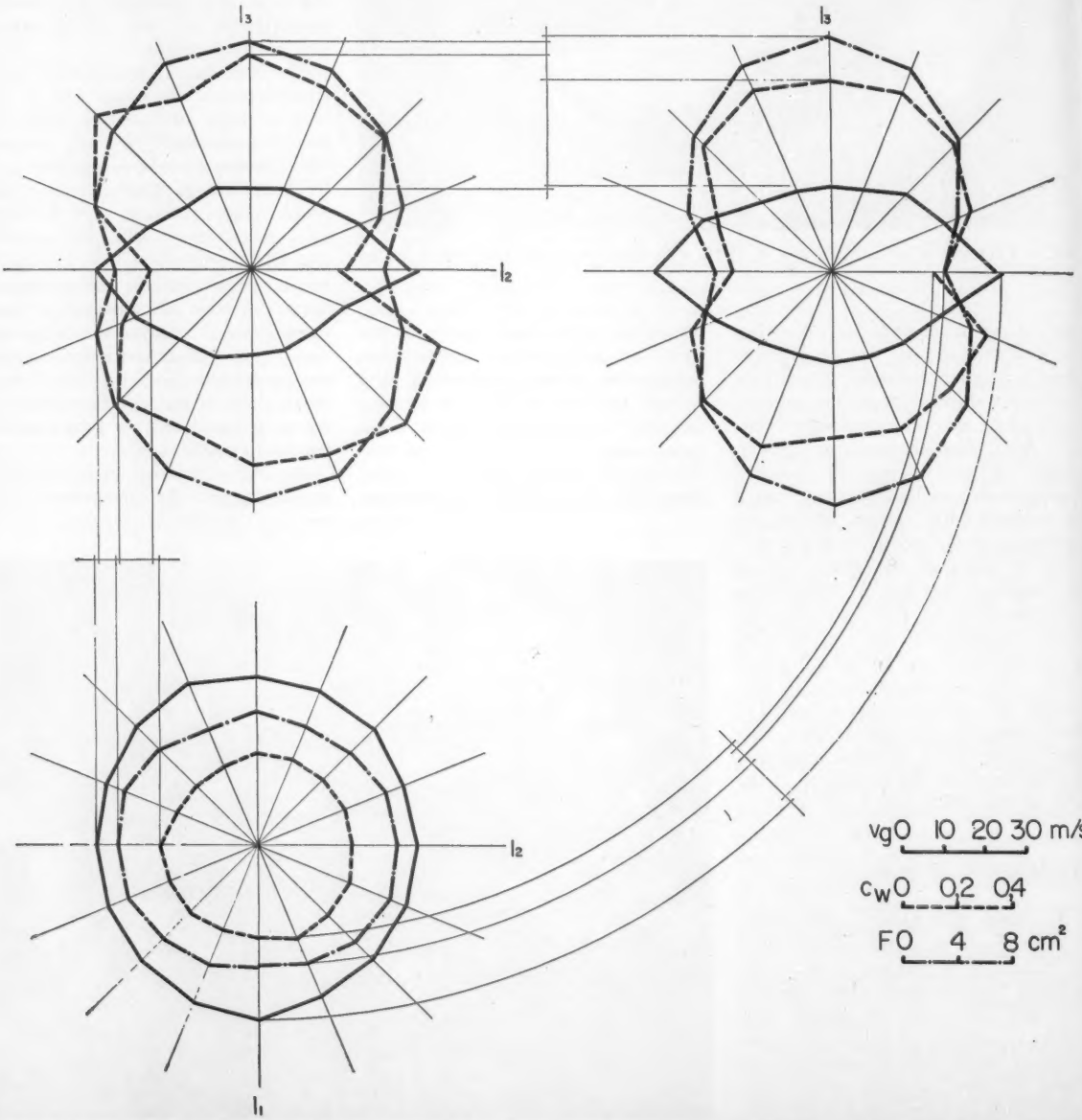


Fig. 5. Drag coefficient C_w, projection plane F, of hailstone No. K 47.24 in the direction of fall, and terminal velocity v in air, as a function of the position of free fall. Longest axes, l_3; shortest axes, l_1; medium axes, l_2.

which is valid for smooth spheres has also been entered and may be regarded as an extreme limiting condition.

From all these statements it follows that, in terms of aerodynamics, natural conditions turn out to be much more favorable for the formation of large and heavy hailstones than deductions based on theoretical considerations would lead one to suppose.

The Experimental Wind Tunnel

All practical work hitherto has treated hailstones as temporally stationary particles. As soon, however, as we want to examine their temporal behavior in a cloud with supercooled water—that is, in conditions where they can grow—we must create artificial atmospheric conditions of the kind that could occur in a storm cloud. This was accomplished by means of the hail tunnel, which is essentially nothing more than a wind tunnel having a closed circuit and an adjustable climate. Its construction is shown diagrammatically in Fig. 8. The actual section used for experiments is a measuring place in which the test object is either suspended or "floated" (where this is possible). To indicate the main features of the tunnel's performance the following figures may be given (*15*): temperature range, $+30°$ to $-65°$C; maximum temperature change in either direction in 1 minute, $\pm 25°$C, provided that the air speed amounts to 10 meters per second; maximum air speed, 80 miles per hour; free-water content of the air, up to 30 grams per cubic meter (that is, values considerably greater than are to be expected in a storm cloud); variation in the diameter of the drops, 1 to 100 microns. The water can be supercooled according to need down to $-35°$C without its becoming frozen; spectra of the ice-forming nuclei are available.

The conditions described can be not only produced but also satisfactorily measured and regulated—as a rule an even more complicated undertaking. The reason for this is that supercooled drops of water moving with the stream of air freeze as soon as they encounter obstacles, whether these are measuring instruments or other objects. An impression of the construction of the plant may be gained from Figs. 9 and 10. Figure 9 shows the actual control unit, from which all apparatus is operated and all measurements and recordings are carried out. In addition, the test object itself, the artificial hailstone, can be observed in its growth from the same place (the measuring place appears on the left in Fig. 9) through a Plexiglas window. Figure 10 shows an ascending section of the wind tunnel below the measuring place, where the water is injected (at rear). On the right of the tunnel stands the refrigerating compressor.

Results Obtained So Far from the Hail Tunnel

The value of this plant will be determined by the extent of the new knowledge which can be gained from it with regard to hail formation. It already promises well, to judge from the first experiment, which has brought to light an apparently somewhat strange

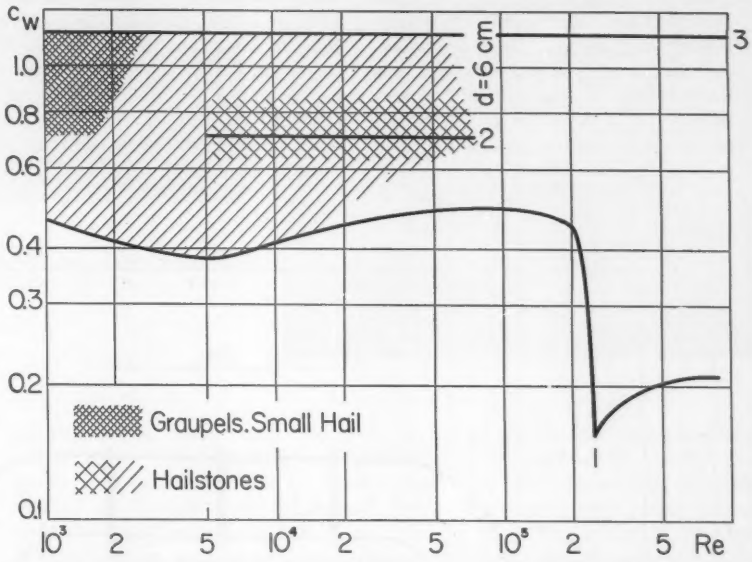


Fig. 6. Drag coefficient of graupels and hailstones as a function of the Reynolds number *Re*. Curve 1, values for smooth spheres; curve 2, values for ellipsoidal hailstones; curve 3, the drag coefficient for plates, giving an upper limit.

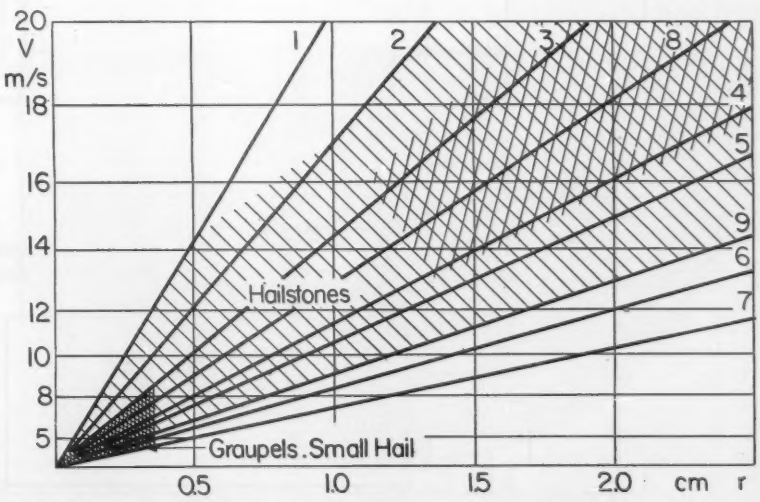


Fig. 7. Fall velocity of hailstones of different shapes: (1) sphere, density $\delta = 0.8$ g/cm³, $C_w = 0.5$; (2) sphere, $\delta = 0.8$ g/cm³, $C_w = 0.7$; (3) sphere, $\delta = 0.8$ g/cm³, $C_w = 1.0$; (4) sphere, $\delta = 0.5$ g/cm³, $C_w = 1.0$; (5) cone, angle 90°, $\delta = 0.8$ g/cm³, $C_w = 0.8$; (6) cone, angle 90°, $\delta = 0.5$ g/cm³, $C_w = 0.8$; (7) cone, angle 70°, $\delta = 0.5$ g/cm³, $C_w = 1.0$; (8) triaxial ellipsoid, $\delta = 0.8$ g/cm³, $C_w = 0.7$; (9) triaxial ellipsoid, $\delta = 0.8$ g/cm³, $C_w = 1.4$.

phenomenon: the growth of conglomerations of ice and water, which may be referred to conveniently as "ice-water mixtures."

What these ice-water mixtures are and how they grow can best be explained by telling the story of their discovery. If a spherical obstacle becomes covered with ice, then a quite definite ice deposit can be brought about, according to the icing conditions (temperature, air speed, free-water content, and so on). Thus, in one experiment a plate-shaped structure was formed with a diameter of approximately 20 centimeters and thickness of between 2 and 4 centimeters. The original diameter of the sphere was 8 millimeters. Since it could be seen that the surface of this growing ice structure was wet, the liquid film on the surface was dried by freezing before the plate of ice was taken out of the tunnel. When we came to remove it, it appeared that our hands were perhaps getting wetter than might normally have been expected, but no conclusions were drawn from this. Afterwards the test object was stored on a table in a cold laboratory at $-10°C$. Half an hour later it was found that the space between the curved undersurface of the ice plate and the table was filled up with ice. The only thing which could have been responsible for this was water built into the ice, which had subsequently worked its way out through capillary systems. This fact contradicts all the assumptions made in the past, from Schumann (*3*) to Ludlam (*13*), who have asserted that only as much water can be gathered by accretion onto a growing hailstone as can freeze. Of necessity, it was supposed, all superfluous water was removed from it by the air stream. This was assumed in contradiction to nature, although no trace of water returned back into the air stream could ever be observed in hundreds of experiments on spheres of diameter up to 2.5 centimeters, speeds up to 80 miles per hour, and water content up to 20 grams per cubic meter (*14*).

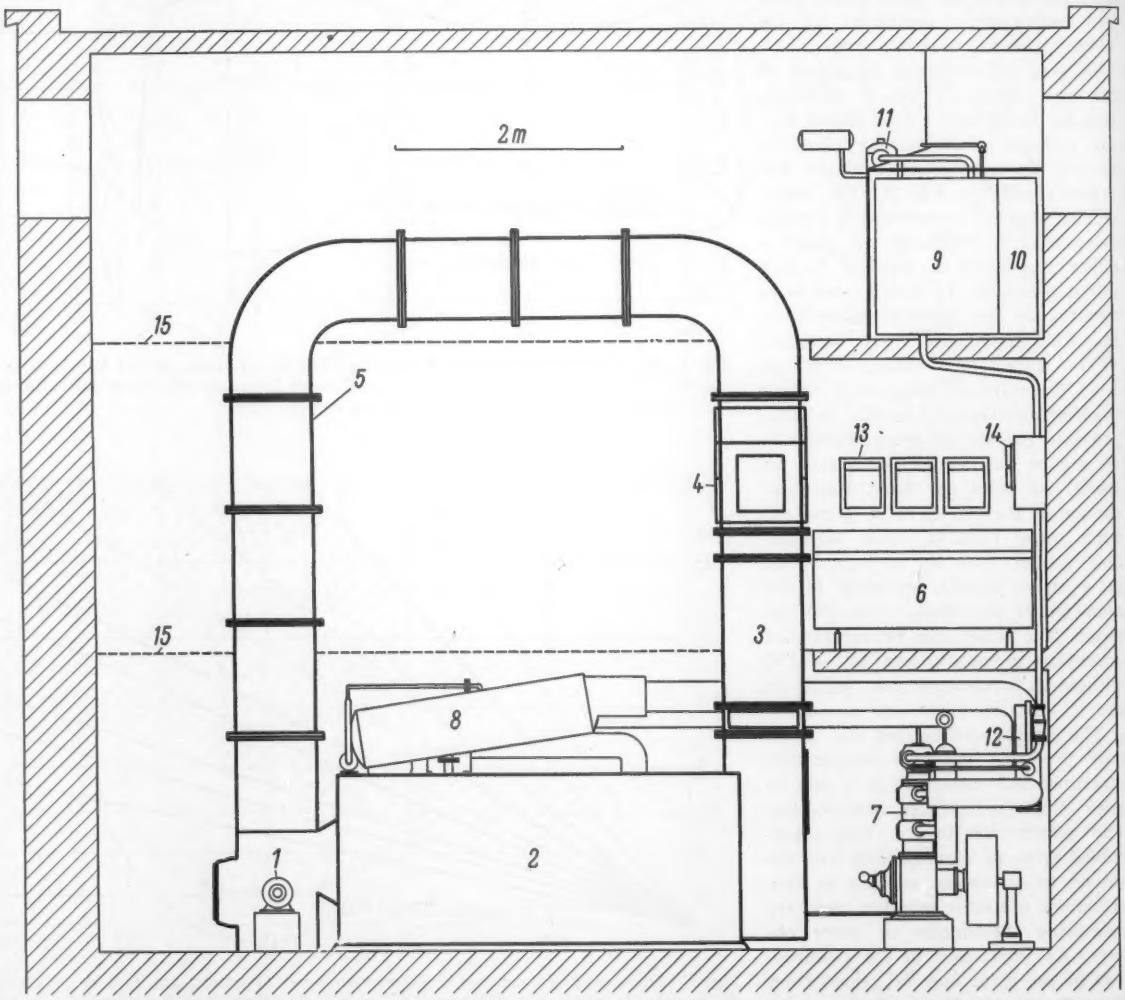
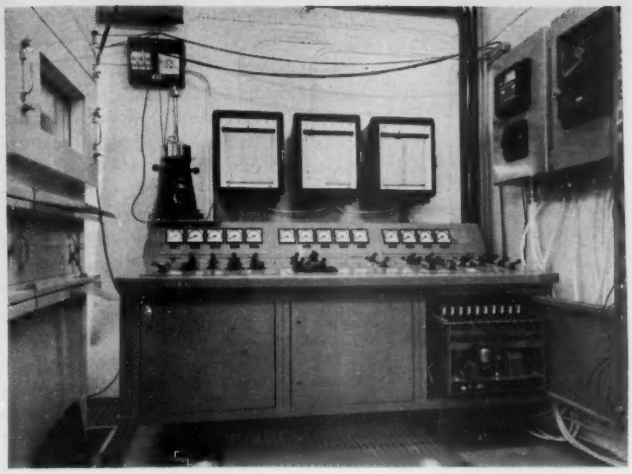


Fig. 8. The Swiss hail tunnel. (1) Blower; (2) section with refrigerating, heating, and filtering elements; (3) drop injection; (4) measuring place; (5) section for bringing the circulation back to the blower; (6) control panel; (7) refrigerating compressor; (8) liquid separator; (9) ammonia condenser; (10) alcohol-water cooler for cooling the refrigerating compressor; (11) oil separator; (12) motor valve; (13) compensating recorders; (14) regulating system for temperature; (15) floors.



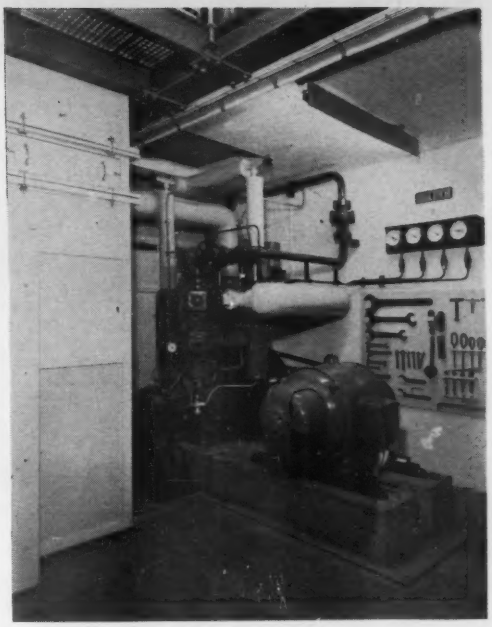


Fig. 9 (top). The measuring section of the tunnel, the control panel, the compensating recorders, and the regulating systems. Fig. 10 (right). The refrigerating compressor.

This example shows again that one's concern must always be with the actual way in which nature behaves rather than with the rationality of human ideas.

The conditions leading to the formation of such ice-water mixtures signify that the total amount of cold administered to the icing object (directly by heat conduction, indirectly by exchange of material as well as by the deposited supercooled water) is not sufficient to freeze all the water that is accreted.

A number of considerations indicate that only one structure is possible where there is steady accretion of water: an ice framework resembling a sponge whose holes are filled with water. And according to the ratio between the cold added and the heat of fusion of all water deposited, the ice walls become thicker or the capillary systems with their water become smaller in extent. By contrast with the superimposition of two growth phases, mentioned above, where a loose ice framework subsequently became filled with water, there is here a parallel growth of ice and water together. It is even possible to show that in fact the water skin grows against the air stream and that subsequent stabilization takes place as an ice framework grows after it. A more extensive series of experiments was made in this connection, during which water was obtained either calorimetrically or by means of a centrifuge. The ice structure of an ice-water mixture formed under the given conditions appears, as indicated in Fig. 11, after the water has been removed. What has so far been learned from this procdure can be summarized as follows. (i) Where hailstones grow in a supercooled cloud it can be shown that normally liquid water is incorporated in the ice particle. (ii) The proportion of liquid water in a single growth phase depends on the total heat exchange with the environment. The proportion increases with increasing values for temperature, free water content, air speed, and the diameter of the icing particle (*14*).

At the same time one should ask

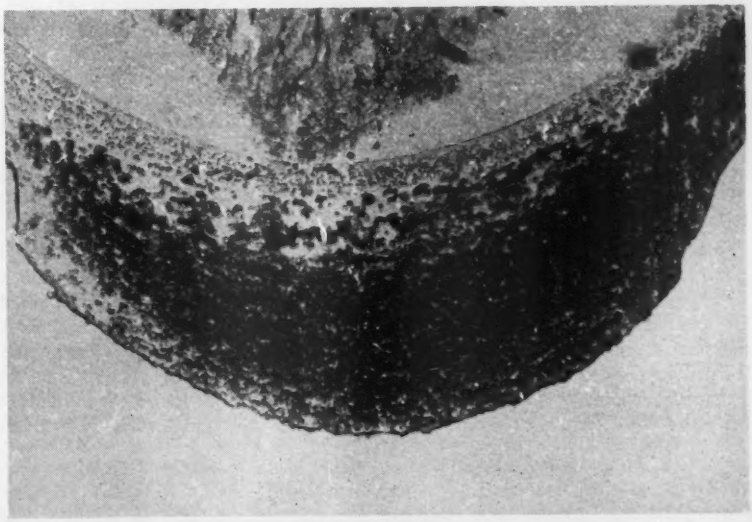


Fig. 11. Ice framework of an ice-water mixture, grown on an initial ice sphere with a diameter of 2.0 cm. Growing conditions: air temperature, —30°C; air velocity, 24 m/sec; free-water content, 8.1 g/cm^3; resulting water content, 19 percent of the total deposit.

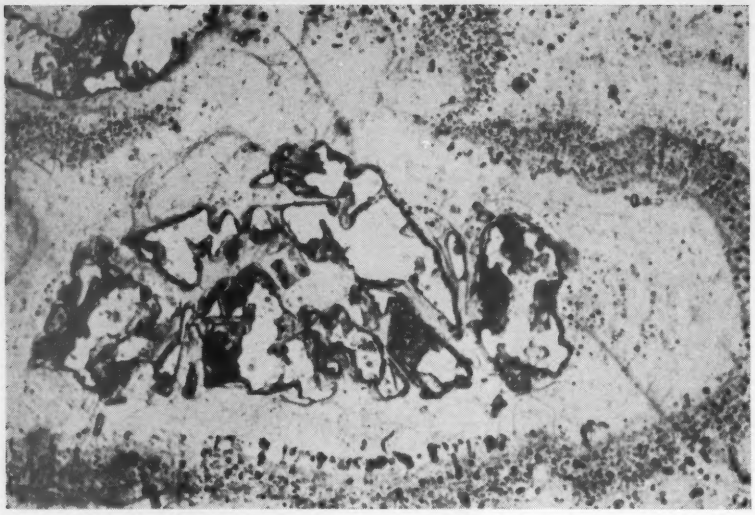


Fig. 12. Hailstone No. K 59.2. Diameter of the cavity, 15 mm; height of the cavity, 5 mm.

whether such watery hailstones are actually observed in nature. For the present the answer is in the negative, for the simple reason that such hailstones had not been expected, and the necessary apparatus for establishing their existence has never been available. Moreover, water which slowly runs out of a hailstone is considered to result from melting. There are, however, indications in the reports of collectors on the mechanical behavior of hailstones that suggest ice-water mixtures. It has been reported possible, after a hailfall, to break apart hailstones which could also split on hitting the ground, as they often do because of low mechanical cohesion. But when similar unbroken hailstones had been kept in a deep freeze, it was quite impossible to break them any longer by hand. This change may clearly be attributed to a solidification of the liquid water present in the capillary systems.

Also found are hailstones with large caverns in them which, it may be concluded, were originally zones formed almost exclusively by liquid water. At a stage subsequent to this formation the water flowed out, and structures resulted of the kind shown in Fig. 12. Virtually identical caverns can also be produced artificially in the growth of ice-water mixtures. Hailstones and artificial ice structures can at the same time exhibit ice crystallites, rather like stalactites, inside such caverns.

In the next few years, however, still greater efforts will have to be made in order to establish definitively, by calorimetric methods or by means of a centrifuge, exactly how much water natural hailstones can contain.

Conclusions

A central problem in every physical hail theory has hitherto been that of calculating the time required for the formation of a hailstone. It was generally felt that in certain circumstances the growth, for example, of an ice particle of 4-centimeter diameter would have to take place (in an extreme case) within 10 to 15 minutes; this was confirmed by radar observations, but no actual values of this order could be got by calculation. The effective relationships, which have been described above, make it possible to show that the ice growth occurs much more quickly than had been supposed under the old assumptions. The factors which help to bring this about are: (i) considerably larger increments of growth, since the water deposited on a hailstone in liquid form contributes progressively to the enlargement of the particle; (ii) an increase in the amount of the deposits as a result of the hailstone's having most frequently, according to observations, the form of a flat ellipsoid (the product of the plane of projection against the air stream and the speed of fall is improved, and this allows more drops of water to be caught); (iii) the hailstones remain longer in zones of heavy ice deposit as a result of a reduced speed of fall, due either to more favorable shape or to greater surface unevenness of the hailstones.

At the same time, we should clearly recognize that all too many points still remain obscure and that these new effects, even if they can be to some extent formulated mathematically, in no wise present an adequate basis for a new, reliable, physical hail theory. For years to come experiments and tests will have to be made, designed to shed light on all aspects of the growth of hailstones. To what extent electrical forces play a part cannot now be said; they are by no means unimportant, however, for under certain icing conditions in our wind tunnel we were able to observe lightning discharges from the icing particle to the environment (*16*).

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16. The work described here was carried out as part of the research program of the Swiss Committee for Hail Research and Hail Defense. Grants were also made available by the Swiss National Foundation.

Searching Natural Language Text by Computer

Machine indexing and text searching offer an approach to the basic problems of library automation.

Don R. Swanson

What is information retrieval?—"Hypothesis after hypothesis has been tried, and still we can't find out. Yet we must never lose hope; more and more complicated theories, fuller and fuller collections of data, richer rewards for researchers who make progress, more and more terrible punishments for those who fail—all this, pursued and accelerated to the very end of time, cannot, surely, fail to succeed."—C. S. LEWIS, *The Screwtape Letters.*

It is through the medium of libraries that knowledge is preserved for the future, yet posterity stands to benefit little unless such preserves are both accessible and digestible. Rather little is known in terms of scientific "observables" about the true usability of library-preserved information; the following brief description of the problem is intended to make evident some important aspects of this ignorance.

A scientist who nowadays imagines either that he is keeping up with his field or that he can later find in the library whatever may have escaped his notice when it was first written is a victim of what might be called the "fallacy of abundance." The fact that so much can be found on any subject creates an illusion that little remains hidden. Although library searches probably seem more often than not to be successful simply because a relatively satisfying amount of material is exhumed, such success may be illusory, since the requester cannot assess the quantity and value of relevant information which he fails to discover.

The sheer abundance of recorded knowledge and the growth rate thereof, furthermore, seem to foreshadow a crisis of inundation. It is estimated that there are now 100,000 journals and 600,000 scientists in the world, and that these quantities are doubling every 10 to 15 years. If this rate of increase is sustained until the tercentenary of this article, there will then be over seven times as many scientists as there are people, a circumstance which should at least provoke (if not stagger) the imagination. The implied *Warmetöd* of scientific information might be forestalled by engineering breakthroughs, but such breakthroughs may depend first on acquiring deeper understanding of the conceptual nature of the problem itself.

The question of formulating criteria for judging the relevance of any document to the motive, purpose, or intent which underlies a request for information is profound and lies at the heart of the matter. The hierology of research on "information retrieval" from libraries is well documented with reported "experiments" whose results generated little more than an aggregate of conflicting opinions on whether any given document, after recovery, was or was not really relevant to the intent of the requester, even though it fulfilled all specified "search criteria." The carrying out of such search experiments when "relevance" per se cannot be consistently assessed by human judgment would seem to represent overly vigorous pursuit of a solution before identification of the problem. Questions of determining "relevance" and "responsiveness," so far as practical purposes are concerned, receive dominant emphasis in the research reported here.

Consider for a moment a "thinkable" solution to the whole difficulty. Clearly, if the requester himself could read all existing literature (that is, every page of the entire library collection) and apply to each piece of information found therein expert intuitive criteria in order to ascertain its relevance to the requirement at hand, there would be, in principle, no problem of communicating recorded knowledge; the procedure suffers only from total impracticality. The historical answer to such impracticality is of course to organize, classify, index, and catalog the library and then search only a very small amount of catalog-type information. (Thus, it is an obvious though sometimes unappreciated fact that indexes and card catalogs for libraries need exist only because libraries are too large to be read through for each information requirement.) In short, some kind of condensed "representation" of the contents of the library is created. This representation, since it is condensed, is necessarily imperfect; the price paid for the convenience of having a practical and manageable search capability is the loss of at least some (and quite possibly most) of the accessible information in the library.

Now, it is a remarkable fact that the extent of information loss for existing libraries is not only unknown but apparently no serious efforts have ever been made to define such loss in measurable terms. Intuitively, one knows that the larger and more detailed the index and catalog, the less the information loss but the greater the difficulty of searching. Indeed, in the extreme, if each sentence of each article of the collection were cataloged, the "representation" of the library so created might approach high fidelity but would be almost as impractical as the library itself for conducting searches.

The matter of impracticality notwithstanding, to suppose that fully successful catalog search is a possibility implies that all human knowledge can be organized by means of some immutable and unambiguous classification or indexing scheme. Apart from the cardinal disadvantage of being nonexistent, such a hypothetical scheme has the even more unfortunate attribute of requiring that information be cataloged with precognition to insure recoverability in response to all conceivably relevant future requests. Both human knowledge and language change in the course of time, and the basic function of the library—to serve as a communication link be-

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tween past and future—cannot, within the framework of present indexing and searching concepts, accommodate such change.

Even though a theoretically complete "solution" to the whole problem of communicating knowledge is thus almost unthinkable, progress in a practical sense constitutes an objective deserving of serious scientific attention.

Equivalence of Text Searching To Automatic Indexing

The purpose of this article is to present and discuss a fundamental approach to the investigation of automatic indexing and retrieval and to report the results of preliminary experiments on the searching of text. It is thus important first to make clear the relationship between text searching and automatic indexing.

Consider again the aforementioned suggestion that, ideally, the full text of the entire library ought to be read and searched for each request, to make certain that nothing relevant is overlooked. The task, for a human being is, of course, impractical to the point of absurdity. Such is not necessarily the case if a computing machine of sufficiently large capacity, high speed, and low cost were to perform the search. Let us suppose such a machine to be available, and for our present purposes let us neglect matters of speed and cost altogether, for the purpose of emphasizing the conceptual problems that are of paramount importance.

It may be seen, after some thought, that "direct retrieval" through searching the entire collection by computer to discover all information relevant to an inquiry is not necessarily possible in principle. That is to say, there is no known machine method for processing the full text of an unindexed document to determine whether that document is or is not relevant to some stated inquiry.

But now consider the full text of a library as the extreme case of a complete index or catalog—namely, a representation in which there is no loss of information. Clearly, if a computer technique for search and retrieval from the full text of a collection of documents cannot be developed, then it is unthinkable that matters could be improved by using the machine to operate on just part of the information (a "condensed representation")—that is, on an automatically produced index. This line of argument demonstrates persuasively that the development of techniques for automatic full-text search and retrieval is prerequisite to automatic indexing. It is equally clear that a technique for automatic indexing can be derived immediately from a text-searching technique, and thus that the two processes involve conceptually equivalent problems. For it is necessary only to so organize the machine procedures that those operations of text reduction or reorganization common to all searches are performed just once, and prior to searching, in order to create directly an automatic indexing procedure.

The practicality and economy of automatic indexing can then be investigated in the light of a known and controllable trade-off between information loss and brevity of representation. It is not suggested that present computers are necessarily economical for library text searching; this study has thus far been addressed to the conceptual problems alone. Questions of economics will be deferred until the process to be mechanized has been defined and understood.

A Model Information System

Let us take as a novel point of beginning the users of the library and their information requirements.

At first sight it would seem not altogether unreasonable to collect and study a large number of questions that have historically been asked of librarians and libraries. However, such questions necessarily reflect not the asker's "requirement" so much as his translation of that requirement into a form to which he thinks the library has a capability of responding. Now, perhaps one could determine the motive or purpose which prompted each request, but even then it is not unthinkable that these motives are to an unknown extent linked indissociably with the user's concept of the library's ability to serve his needs. The danger of beginning with the library query rather than the motivating requirement is apparent from the fact that the relevance of a library document to some request depends on the viewpoint and purposes of the requester.

Thus, in the experiments discussed here the "information requirement" of the requester is based on a set of questions constructed without reference to library experience. These questions are highly specific and, to the extent possible, incorporate within themselves the requester's "viewpoint" and "motive." Examples of such questions are: (i) What nuclear reactions are sensitive to the spin and parity of mesons and hence are useful in measuring those quantities? (ii) How does charge polarization within a nucleus affect the Coulomb scattering of charged particles by that nucleus? (iii) What are the "magic numbers" for nuclear shell structure?

A collection of 100 articles was chosen as an experimental "library," and each article in the entire collection was studied in the light of its possible relevance to each of 50 questions asked. Degrees of relevance were recognized, and a weighting factor was estimated to represent such a degree. The subject matter of the articles was restricted to nuclear physics, and relevance estimates were made by physicists with postdoctoral experience in the specialties represented by the articles. This procedure thus led, insofar as is conceivably possible, to prior determination of all relevant responses to any subsequent retrieval question. Confidence in the process is based upon the fact that a satisfactory degree of consistency among independently rendered judgments as to relevance resulted.

The restriction of the collection to homogeneous subject matter was intended to permit some degree of extrapolation to the behavior of larger collections. Computer search techniques must necessarily be based on the language content of the documents searched, and it is clear that the more homogeneous the language the more difficult the problem of discriminating relevant material from irrelevant for any given request. Thus homogeneous subject matter in a small collection would tend to present about the same level of retrieval difficulty as diverse material in a larger collection.

In effect, a "model" information system was adopted which consists of a small collection of articles, a list of questions, and a matrix of numbers representing the estimated degree or "weight" of relevance of each article to each question, based on careful application of expert human judgment. Within the framework of this model any method of information searching can be tested for its ability to yield relevant documents and reject those that are irrelevant. The scope of the investigation at present is based solely on the hypothesized model. Experiments and conclusions apply to the model only; the

relationship of the model to reality is a separate matter involving a multitude of complex issues that will be dealt with in the course of time as understanding of the behavior of the model grows, and as reasons emerge for introducing modifications.

Experience thus far has indicated that this first model is neither too elementary to be challenging nor too complex to be manageable. In contrast to real information systems, the "observables" have been identified and the imponderables have been expunged—at least to an extent sufficient for practical purposes.

The latter point deserves some amplification. Information retrieval is not likely ever to become a precisely defined process (in a "formal" or mathematical sense) so far as machine procedures are concerned, and at best one can hope to achieve only partial success. The futility of seeking rigor and precision should not cause one to abandon pursuit of maximal understanding of the nature of the problem. It is this basic understanding which is sought in the investigation of a simple model, so that sound approaches toward the development of economic, effective, and practical large-scale information systems can then be initiated.

Text-Searching Experiments

To construct the model system described in the preceding section and to carry out the search experiments, two separate teams of physicists were formed. Group 1, through direct study of each article in the collection, determined its degree of relevance to each question asked. Group 2 was assigned the task of transforming each question into a search instruction for the computer. No member of group 2 was permitted any knowledge of the contents of the search library other than that it was made up of 100 nuclear physics articles selected from the *Physical Review* over a 10-year period.

Group 2 consisted of seven persons: three nuclear physicists, two computer programmers, one mathematician, and one librarian (with training in physics). Each of these seven persons formulated search instructions for each of 50 questions, using the three methods described in subsequent paragraphs. Thus, about 1000 retrieval experiments were carried out.

To illustrate the character of the search instructions, consider that into which the second of the three example questions listed above might be transformed: Deliver all articles which contain either the phrase *charge polarization* or *charge distribution* and at the same time contain the word *scattering*, *scattered*, or *scatter*.

The computer program utilized has a capability for testing each article in the collection to determine whether or not the conditions of the search are met. (The full text of each article was keypunched and recorded on magnetic tape.) In essence, an article can be tested to determine the presence of any given word, any one or more of a group of words, or the simultaneous presence of one (or more) members of each of several groups, as illustrated in the foregoing example. Phrases may be used instead of words in any part of the specification. For each article which satisfies the required conditions, the computer supplies a printed output which indicates the location of each of the discovered words or phrases within the search list.

The library (on magnetic tape) searched by the computer was not in any way indexed, classified, or organized by human processing. The experiments did not include searches for authors or reference citations.

In order to compare the effectiveness of text searching by computer with more or less conventional methods of using libraries, the experimental collection of articles was cataloged by means of a subject-heading index designed especially for the field of nuclear physics. The physicists of group 2, assisted by technical librarians, transformed each of the test questions into appropriate index entries in order to search the card catalog.

The success of machine retrieval and conventional subject-heading retrieval was measured in terms of the "direct examination" process carried out by the members of group 1. These measures of success take into account both the fraction of relevant material retrieved and the amount of accompanying irrelevant material.

Thus, the evaluation procedure is intended to establish some measure of the effectiveness with which human beings can transform questions into computer search instructions and to permit comparison of full text search with a conventional subject-heading catalog search. Of greater importance are the objectives of determining the extent to which the effectiveness of full text search can be improved through use by the requester of certain "retrieval aids," such as a thesaurus, and of developing techniques for systematically improving these aids as a result of collecting experimental data. Machine search experiments were carried out both with and without retrieval aids, and the two cases were compared.

The three methods of retrieval employed are designated by the following symbols and definitions. (*C*) "Conventional retrieval" based on a subject-heading index; no machine procedures are involved. (*U*) Retrieval based on specifications of words and phrases in disjunctive and conjunctive combinations, as illustrated above. No retrieval aids are employed (*U* denotes unaided). (*A*) Search requests are formulated as described for *U* but with the thesaurus-like word and phrase group list and the index thereto as retrieval aids.

Each individual completed formulating search instructions for condition *U* before undertaking *A*, since otherwise *U* might be invalidated by recollection of the retrieval aids employed in *A*.

Use of a Thesaurus

The process of formulating a computer search instruction from the posed question consists of conjecturing lists of possible words or phrases which the requester believes responsive material ought to contain and nonresponsive material ought not to contain. He must be alert to different ways of expressing the same concepts and to the frequency or commonness of the words or phrases which he chooses. Potentially the retrieval aid of most use to the requester should be a collection of thesaurus-like groupings of words and phrases which tend to mean about the same thing for most foreseeable purposes of information retrieval and which can be used to stimulate his memory in the process of constructing "alternate ways of expressing the same concept."

Such a thesaurus for nuclear physics words and phrases was compiled for the purpose of these experiments. The use of this thesaurus can best be illustrated by an example. Suppose that in order to formulate a search instruction from the question "What are the magic numbers for nuclear shell structure?" the requester first conjectures that, although a search for the phrase *magic numbers* would no doubt be productive, there

might be relevant articles which do not contain that phrase and, indeed, perhaps articles that were written before the phrase was invented. Thus, in order to be reminded of words or phrases in addition to *magic numbers* which might be clues to the presence of information relevant to the question, he consults the thesaurus by means of an index. He looks up the word *magic* and is referred to thesaurus group 0311 consisting of the list of words and phrases illustrated in Fig. 1. Among other things, he is reminded of the appropriateness of the concept of stability (*stable nuclear species, nuclear stability, particularly stable*) and somewhat less directly of the implication that an unusually high abundance connotes unusually high stability. On the basis of these reminders he designs an appropriate search instruction.

The thesaurus and other retrieval aids were compiled with the aid of text from a sample library that did not contain any of the search library documents, although, as in the latter, the subject matter was restricted to nuclear physics. It was hoped, of course, that the sample library would be useful as an aid to constructing the language relationships that form an essential part of the retrieval aids to be tested by using the search library. Had the search library itself been used to compile thesaurus-like word groups, then the particular relationships existing within the search library, and perhaps highly peculiar to that library, would become so readily apparent to the searcher that almost complete success in retrieval would be a foregone conclusion; the experiments in this circumstance would have had little scientific validity. This observation is particularly important in view of the small size of the search library.

PAGE 21
GROUP 0311

DOC	M									
037	1	ABUNDANT			NUCLEAR			SPECIES		
047	1	CLOSED			SHELLS					
070	4	EVEN		ATO	MIC			WEIGHT		
047	1	EVEN			NUMBER		OF	IDENTICAL		NUCLEONS
048	1	EVEN			NUMBER		OF	IDENTICAL		NUCLEONS
082	4	EVEN-EVEN			CORE					
111	2	EVEN-EVEN			NUCLEI					
084	2	EVEN-ODD			COMPOUND			NUCLEUS		
100	1	EXCITED			STATES		OF	EVEN-EVEN		NUCLEI
110	4	EXCITED			STATES		OF	EVEN-EVEN		NUCLEI
041	1	FUNCTION		OF	ATOMIC			NUMBER		
070	4	LIGHT			MIRROR			NUCLEI		
037	1	MAGIC			NUMBERS					
047	1	MAGIC			NUMBERS					
048	1	MAGIC			NUMBERS		IN	NUCLEI		
037	1	MAGNETIC			MOMENTS		OF	ODD		NUCLEI
100	1	MAGNETIC			MOMENTS		OF	ODD-NEUTRON		NUCLEI
100	1	MAGNETIC			MOMENTS		OF	ODD-PROTON		NUCLEI
036	2	MASS			NUMBER					
057	1	MASS			NUMBER					
056	1	MASS			NUMBER			REGION		
057	1	MASS			NUMBER			RANGE		
057	1	MASS	5		UNITS					
050	1	MIRROR			NUCLEI			LI7	AND	BE7
101	2	MIRROR			NUCLEUS			HE5		
050	1	MIRRORED			COUNTERPART		OF	EXCITED		STATE
041	1	NEIGHBORING			HEAVY			ELEMENTS		
057	2	NEUTRON			DEFICIENT			BISMUTH		ISOTOPES
047	1	NEUTRONS	5							
057	1	NEUTRONS	5							
057	1	NUCLEAR			STABILITY					
057	1	NUCLEI								
036	1	NUCLEI		IN	REGION		OF	NEUTRONS		
037	1	OCCUPATION			NUMBERS					
082	4	ODD			NEUTRON					
037	1	ODD			NUCLEI					
047	1	ODD			NUMBER					
048	1	ODD			NUMBER		OF	IDENTICAL		PARTICLES
100	1	ODD-EVEN			NUCLEI					
084	2	ODD-ODD			COMPOUND			NUCLEI		
047	1	ODD-ODD	5		NUCLEI					
110	4	ODD-PARITY			STATES					
047	1	PARTICULARLY			STABLE					
037	1	PERIODIC			SYSTEM		OF	ELEMENTS		
047	1	PROTONS	5							
057	1	PROTONS	5							
100	1	SINGLE			ODD			NUCLEON		
047	1	SINGLE			ODD			PARTICLE		
047	1	SPINS	5	OF	ODD			NUCLEI		
037	1	STABLE			NUCLEAR			SPECIES		

Fig. 1. A thesaurus group.

Results

Data on retrieval results are presented in terms of a scoring algorithm which depends, as mentioned above, on the percentage of relevant material retrieved and on the amount of irrelevant material also retrieved. The relative weight given to these two factors is arbitrary and represents an intuitive estimate of the relationship between "reward" for successful retrieval and "punishment" for irrelevant retrieval. The penalty for irrelevant retrieval we take proportional to the "cost" (in terms of time spent) of reading the irrelevant document. The retrieval score, then, is given by $(R - pI)$, where R is the sum of the relevance weights of the retrieved documents divided by the total sum of the relevance weights (for the given question) of all documents in the library; I is the effective amount of irrelevant material (and is given by $N - LR$, where N represents the total number of documents retrieved and L represents the total number of relevant documents in the library); and p is the irrelevance penalty and may take on arbitrarily assigned values. The scoring formula can be derived by taking a linear combination of the fraction of all relevant information retrieved and the cost of reading all retrieved material and then normalizing so that the score for "perfect" retrieval (all material which is relevant plus none that is irrelevant) is 1.

Results have been compounded into a single score; such a compound score facilitates comparisons for different individuals and comparison of different methods of retrieval. The sensitivity of the various scores (averaged over 50 questions) to the factor p is of especial interest, and a graph showing this relationship is presented in Fig. 2. The $p = 0$ intercept shows the percentage of relevant retrieval, while the slope is directly proportional to the amount of irrelevant retrieval.

The first conspicuous implication of the results is that the proportion of relevant information retrieved under any circumstances (intercept for $p = 0$) is rather low. Though wide variation of success within the 50 questions was encountered, for no single individual did the average amount of relevant material (that is, the summed weight factors) retrieved (taken over 50 questions) exceed 42 percent of that which was judged by the members of group 1 to be present in the library. It is clear that in

a library consisting of only 100 documents a fairly heavy penalty should be assigned to irrelevant retrieval. Intuitively, it seems reasonable to assume that p ought to lie in the range 0.05 to 0.15; unless otherwise specified, comparison of data will be based on that assumed range.

A second implication of the data in Fig. 2 is the apparent superiority of machine-retrieval techniques over conventional retrieval within the framework, of course, of our model. Conventional retrieval was carried out under the favorable conditions of a highly detailed and specific subject-heading list, tailored to the sample library, which in turn was selected from the same journal (the *Physical Review*) as the search library (but which contained no documents in common with the latter). The assignment of subject headings to the documents was liberal, with an average of about five headings per (1000-word) document; the number ranged up to 14. However, the assignment was not based upon knowledge of the search questions themselves, nor was it intended to exhaustively identify all conceivable subject relevancies.

A still greater margin of success of text search over subject retrieval was provided by what may be called the "source" documents. Each of the 50 questions was inspired by some particular document within the model library; that "source" document was therefore known to be highly responsive (weight 10) to its corresponding question. Because of this direct relationship, all results for retrieval of source documents were separately tabulated and not included in the graphs of Fig. 2. These results, in terms of "percent of relevant material retrieved averaged over all requesters and all questions" can be summarized in the following manner: *C* [conventional (subject heading)], 38 percent; *U* [unaided machine text search], 68 percent; *A* [thesaurus-aided machine text search], 86 percent.

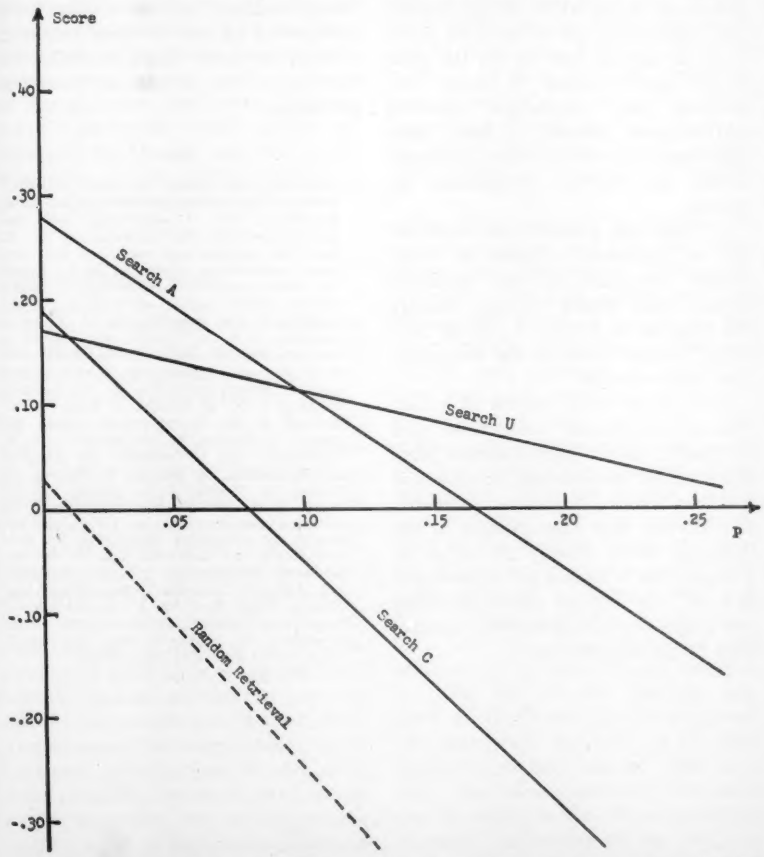

Fig. 2. Mean scores of each search (average of individual mean scores) as a function of the penalty coefficient p. "Random retrieval" is shown for 3.0 documents, the average for all searches.

It is a reasonable surmise that the language of the "source" document may have influenced the language of the question, and hence the language of the search request, thus increasing the prospects for successful text search. Generally, though, it was found that all documents with high relevance weights (whether source documents or not) were proportionately more effectively retrieved by text search; such correlation between high relevance and successful retrieval was less pronounced for the conventional search. Details of these results are given in the reports cited in (*1*).

It is expected that the relative superiority of machine text searching to conventional retrieval will become greater with subsequent experimentation as retrieval aids for text searching are improved, whereas no clear procedure is in evidence which will guarantee improvement of the conventional system, other than purposeful indexing to exhaustion or perhaps the provision of a team of physicists as consultants to the librarian-indexer. For either circumstance it is hardly appropriate to use the designation "conventional."

Although much detailed study still must be carried out to determine, for each question asked, just why relevant information was missed, it seems likely that for the "conventional" case the problem is largely that of a mismatch in viewpoint between indexing and questioning. Subject headings relevant to the questions asked were largely nonexistent.

It is intended to test, in future experiments, the effectiveness of a subject-heading list developed directly from a set of "sample" retrieval questions, separate from but similar to the test questions. It is possible that tailoring an index to user plus library rather than to librarian plus library would result in better "conventional" retrieval, though again the term *conventional* seems to lose its appropriateness.

In general it was found that a thesaurus-like collection of word and phrase groups is clearly of potential use as a source of suggestions, reminders, and stimuli in transforming questions to search instructions. The effectiveness of the physics thesaurus compiled for the first series of experiments was marginal but measurable; of greater significance is its apparent improvability, as indicated by the analysis of the results.

A study is in progress to determine for each question asked the specific reason why relevant information was missed and why irrelevant information was retrieved. The results of partial analysis may be summarized as follows:

1) As was to have been expected for the first experimental cycle, a good many of the failures were due to obvious causes for which there are simple remedies. Inadequate recording of symbols and equations (particularly of subscripts and superscripts), confusion of capital, lower case, and other "engineering" problems accounted for failure to retrieve a significant amount of relevant material. Pure "machine synonyms" (such as π as an abbreviation for π-meson) not foreseen by the requester were encountered quite frequently.

2) A somewhat surprising reason for retrieving certain "irrelevant" information was the fact that such information turned out not to be irrelevant after all. Relevance implications had been overlooked by the members of group 1 in spite of independent assignment of weighting factors by two persons and a resolution of all variances through discussions with a third. The number of variances exceeding 2 weight points (on a scale of 10) was less than 20 percent of the total, for independent assignment, and most of this variance was attributable to obvious oversight. It is inferred that the exposure by machine search of the occurrence of certain words, phrases, and combinations of words and phrases can suggest to the reader relevance relationships that were not apparent beforehand, even with reasonably diligent study. Although this phenomenon was not very frequent, it is clear that the group 1 diligence level should be increased for subsequent experiments, since presumably a small amount of nonretrieved material erroneously received a relevance score of zero.

3) In many cases irrelevant material was retrieved through the conjoint occurrence of words which were not related to one another in the manner intended by the requester. This phenomenon is, of course, well known in any process of coordinating key words. To some degree, however, whenever irrelevant retrieval occurs because of lack of relationship specification, it should be possible to remedy the situation by requiring that certain of the specified terms occur within the same sentence or at least in relatively close proximity to each other. In effect, the substitution of proximity for syntax is suggested; the potential value of this suggestion is being investigated. Preliminary results indicate that, on an indiscriminate or purely statistical basis, proximity is not helpful. All retrieved documents were partitioned into two groups, the relevant and the irrelevant. A search word-proximity parameter was defined, measured, and found to be not significantly different for the two groups.

4) The most difficult problem encountered is that of indirect implication or even pure analogy. On a number of occasions an article which would unequivocally be judged by a physicist to be relevant to a given question would contain no words which, in any reasonably direct way, would be at all likely to be designated relevant on the basis of the question alone. It turned out, however, that conventional indexing and retrieval systems in these latter cases were no more successful in recognizing the relevant associations involved.

5) Irrelevant material was retrieved due to unforeseen contexts of single words. Expansion of the thesaurus phrase index would probably remedy the situation to a large degree by providing sample contexts for frequently used combinations.

6) A rather large amount of missed relevant information would have been retrieved if certain fairly common near-synonyms of the specified search words had been listed as disjunctive alternates. It is obvious that augmentation of the thesaurus would remedy the defect to a degree, but it cannot yet be surmised how far one can go toward building into a thesaurus all conceivable associations of retrieval interest.

Summary

A fundamental approach to automatic indexing and retrieval of library-stored information through investigating machine search of natural language text is described above, and the results of preliminary experimental studies based on that approach (*1*) are presented. A limited and manageable model of a library (together with search questions) constituted the object of the investigation; the effectiveness with which responsive information could be recovered was measured. The small scale of the model permitted direct examination of the entire collection as a basis for establishing practical measures of "relevance" or "responsiveness" to questions.

In terms of these measures, the effectiveness of all information search techniques tested on the model was found to be rather low. Text search by computer was, however, significantly better than a conventional, nonmechanized subject-index method. Thus, even though machines may never enjoy more than partial success in library indexing, a small suspicion might justifiably be entertained that people are even less promising.

Note

1. This work was carried out under the sponsorship of the Council on Library Resources, Washington, D.C. I acknowledge with sincere appreciation the assistance of L. C. Ray, who planned and supervised the computer programming efforts; of J. L. Kuhns, who made invaluable contributions in mathematical analysis and in interpretation of the results and also suggested the C. S. Lewis quotation; of J. M. Fontana, who assisted in the programming; and of D. V. Black, who developed and applied the subject-heading index. I extend thanks also to the members of group 1 (R. W. Wright, A. Risley, J. M. Brabant, L. M. Frantz, A. L. Morse, W. Blocker, L. Higgins, W. Hershberger, and H. Trueblood) and to members of group 2 (D. L. Drukey, R. Norton, K. Watson, J. Mersel, D. Wenger, J. L. Kuhns, and D. Black). I am also indebted to Professor N. Chomsky and Professor P. L. Garvin for helpful and stimulating discussions. For further details and additional data on the experiments discussed see "Word Correlation and Automatic Indexing," *Ramo-Wooldridge Reports; Progr. Rept. No. 1, C82-9U9* (1959); *Progr. Rept. No. 2, C82-0U1* (1959); "An Experiment in Automatic Text Searching," *Phase I Final Rept. C82, 0U4* (1960).

Modern Blasting Agents

Because they are safer, cheaper, and nontoxic, they are replacing dynamites in some operations.

Melvin A. Cook

More than 1000 million pounds of detonating explosives ("high explosives") are used annually in the United States in mining, quarrying, road and railway construction, seismic prospecting, submarine blasting, gas and oil-well shooting, and agriculture, as well as for such novel purposes as jet tapping of furnaces, jet piercing of casings and formations in oil wells, work hardening and forming of metals, and blind riveting (*1*). Until recently the most common explosives have been the dynamites invented by Nobel (donor of the famous peace prizes), which are based on nitroglycerine. But today, "blasting agents"—explosives which cannot be detonated by blasting caps but which require the use of powerful boosters—are rapidly replacing dynamites.

Types of Blasting Agents

The past four years have witnessed the introduction, first in open-pit and recently in underground mining, of several new do-it-yourself blasting agents, the most important of which is "prills and oil," a mechanical mixture consisting roughly of 94 percent fertilizer-grade ammonium nitrate (FGAN or, simply, AN) and 6 percent fuel oil.

A more recent series comprises the "slurry" blasting agents, which consist of coarse TNT and granular ammonium nitrate, and sometimes also sodium nitrate, dispersed in an aqueous solution of ammonium nitrate with only enough aqueous solution to give the mixture the consistency of thick soup. The success of the slurry blasting agents prompted investigations of still other types of slurry. In one type of nonexplosive sensitizers, for example, molasses (*2*), sugar, or heat-producing metals have been substituted for the TNT. In another, both the aqueous medium and the TNT have been replaced by a liquid medium—for example, methylamine or dimethylamine and ammonium nitrate—to accomplish both sensitization and fluidization. In a third type of slurry, TNT has been replaced by a heat-producing metal, such as magnesium, and the aqueous solution by Diver's solution (a mixture of ammonium nitrate and ammonia). While slurry blasting agents representative of each of these types have been used in boreholes of large diameter, none has been as successful as the coarse TNT types which already are being used in the United States and Canada to the extent of several million pounds monthly.

Explosives composed of mixtures of ammonium nitrate and fuel (here *fuel* denotes any nonexplosive, combustible sensitizer) were first contemplated by Ohlsson and Norrbein in one of the earliest patents in the field of high explosives, and explosives of this type have been used extensively during the past quarter century. "Nitramon," the series to which the term *blasting agent* was first applied, is an example of the ammonium nitrate-fuel system. While such explosives have long been recognized as the cheapest source of explosive energy in the modern world, their great economic advantages were not fully realized until the discovery of prills and oil. Plant-formulated and packaged compositions almost identical to prills and oil—for example, one grade of Nitramon—have been in use for many years, but they did not lend themselves to field mixing. Field mixing is readily accomplished with prills and oil, owing to the unique properties of prilled ammonium nitrate, and as a result, savings of up to 75 percent of previous powder costs have been realized.

The field formulation of prills and oil became possible with the invention of the coarse, porous, kieselguhr-coated, "prilled," fertilizer-grade ammonium nitrate. This material was first manufactured as a fertilizer with special wax coatings to prevent caking, but after the great Texas City disaster and similar ones in Brest, France, and in the Black Sea region, caused by the hot bagging of organic-coated, prilled AN, the fertilizer industry turned for reasons of safety to the inert, inorganic, diatomaceous-earth coating. It was the unique absorptive properties of kieselguhr-coated, prilled ammonium nitrate for fuel oil that permitted the successful field mixing of prills and oil which began in 1955 on the Mesabi Iron Range (*3*). Prilled FGAN containing 3.5 percent kieselguhr absorbs rapidly and uniformly without mechanical mixing, but simply by diffusion, up to 6 percent fuel oil, fortuitously rejecting, to a large extent, any excess oil. At first the field mixing of prills and oil was accomplished by pouring into the borehole (around the boosters suspended on a Primacord downline) a bag of fertilizer-grade ammonium nitrate followed by a gallon of fuel oil and repeating until the desired total charge was in place in the borehole. To insure complete detonation, large dynamite or Nitramon primers or boosters were used either at the bottom and top of the shot (Fig. 1*a*) or at frequent intervals along the column (Fig. 1*b*), the boosters being detonated by the Primacord.

Borehole mixing did not prove reliable and soon gave way to surface mixing methods in which oil was sprayed into the ammonium nitrate as it flowed through a funnel or hose into the borehole (*4*) or was poured into open bags of FGAN, several hours or days being permitted for diffusion of the oil into the salt before the mixture was poured in the borehole (*5*). These methods in general depended on the unique ability of the kieselguhr-coated, prilled ammonium nitrate to absorb oil uniformly up to 6 percent and to reject any excess oil. With less absorptive types of ammonium nitrate, impractical products of excess oxygen and low strength generally result; with more absorptive types one must use an excess of oil, and these also yield an insensitive, low-strength product but one deficient in oxygen. Even when one takes special precautions to introduce the right amount of oil into a nonabsorptive type of ammonium nitrate, the oil may

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not distribute itself uniformly in the nitrate with diffusion blending or spraying. The fine-grained types, which are also nonporous because of their high surface area, absorb the required oil in only part of the nitrate, thus causing non-uniformity of diffusion or spray blending. Recently the "Stengel process" ammonium nitrate, a high-density, nonporous type, has been successfully adapted to field mixing of the nitrate and oil through blending an appropriate particle size distribution of the salt (*6*). This technique is equally applicable, but has not yet been used, with other types of ammonium nitrate—for example, those types made by evaporation drying in a graining kettle ("graining kettle ammonium nitrate") or by spraying and drying in a blast of hot air ("spray-day ammonium nitrate") and high-density, nonporous, prilled ammonium nitrate, made by the prilling process but brought to dryness during instead of after prilling.

The need for careful mixing of prills and oil (especially since uncoated and organic-coated, prilled, and various nonporous types of ammonium nitrate have come into extensive use) is currently widely recognized, and many are turning to special mixing systems to obtain uniformly mixed material (*7*). One may easily recognize poorly mixed prills and oil by the characteristic red-dish-brown fumes, in which the products of detonation are colored by excess oxides of nitrogen. One can be sure that products which generate these beautiful reddish-brown clouds will develop appreciably lower strength and pressure than uniformly mixed prills and oil.

Owing largely to its very low density (0.82 gm/cm^3), the prills and oil mixture is really a low-grade blasting agent. Yet its use in bulk where it completely fills a cross section of the borehole (loading density $\Delta = 1.0$), in contrast with packaged explosives, in which the loading density Δ is necessarily appreciably less than unity, has largely offset the disadvantages of low density (*8*).

Unfortunately, the prills and oil mixture is useful only in dry-hole blasting because it is incompatible with water; moreover, its low density prevents it from sinking in water even if it is used in water-tight bags. It was the need to extend field-mixing methods to wet-hole blasting and the idea "if you can't lick it, join it" that prompted the development of slurry (*9, 10*). Aside from water compatibility, the advantages of slurry as compared with prills and oil are its high density (twice the density of prills and oil), which permits it to be used at much higher bulk strengths with accompanying large savings in drilling costs (since fewer or smaller boreholes are required), and up to four times greater borehole pressures, affording much better rock breakage at the bottom of the borehole where breakage is most difficult. Many operators are therefore using slurry even for dry shooting, especially where the rock is hard and difficult to blast and where drilling costs are high. Slurry made with half again as much coarse TNT as that used in formulations designed for holes of 4-inch diameter and greater (Table 1) and carefully oxygen-balanced—for example, by adjusting the ammonium nitrate-sodium nitrate ratio to obtain satisfactory "fumes"—is currently under study for use in underground blasting (*11*) in holes of small diameter (1.5 inch to 3.0 inches).

Blasting Methods

Major advances in blasting methods preceded the prills-and-oil breakthrough. Detonating fuse, first formulated with a lead-bound TNT core ("Cordeau"), became an important blasting accessory with the introduction of Primacord, a cloth- or plastic-bound detonating fuse containing a pentaerythratol tetranitrate core ranging in amount from 1 to 400 grains per foot. Primacord permitted the successful

Table 1. Some properties of the prills-and-oil, slurry blasting agents, and cast boosters as compared with dynamite and fine-grained TNT.

Property	Prills and oil (94/6)		Slurry		Cast boosters		TNT (fine)	Dynamite	
	Guhr AN	Organic-coated AN*	DBA-1†	DBA-2‡	"Procore" 3C	"Pento-Mex"		50% Forcite	75% Gelatin
Density ρ_1 (gm/cm^3)	0.82	0.88	1.52	1.68	1.7	1.65	0.87	1.4§	1.4
Detonation velocity D (km/sec)									
Theoretical	4.2	4.5	6.4	6.8	7.8	7.6	4.7		6.5
D (10 in. borehole)‖	4.05		6.15						
D (5 in. borehole)‖	3.57	3.05	5.17					5.1	
D (5 in. unconfined)#	2.77	2.67	4.9	5.8					6.5
D (1.25 in. unconfined)					7.8#	7.6	4.7	4.4	4.9
Strength									
A (kcal/gm) calc.	815	845	880¶	840¶	965	965	800	720	950
Seismic strength results#	814	850	870¶	860¶			(800)		
Detonation pressure									
p_2 (kbar) calc.	40	48	150	180	219	215	42		135
Aquarium method (5 in. unconfined)**	13.5		85	126	215 (3 in.)	220 (2 in.)	37 (1.5 in.)		
Borehole pressure p_i (kbar) calc.	18	21	75	90			22	49	60
Minimum booster (gm cast pentolite)#	40	5	80	10	††	‡‡	§§	§§	§§
Critical diameter d_c (in.)#	4	4	4	1.25	0.25	0.25	0.25		0.25
High velocity impact# sensitivity (kcal at 50/50 detonation-failure point)	130	15	>2500	500	130				<0.2

* The organic coating referred to here is the product sold under the trade name "Petro-Ag". It is used only to the extent of about 25 parts per million. † 60/15/25 AN/SN/coarse TNT. ‡ 32/32/36 AN/SN/TNT slurries with 10 to 20 parts water, 0.2 to 0.4 part guar gum and sometimes also 0.02 to 0.04 parts sodium borate. § *Blaster's Handbook* (Canadian Industries Ltd., Montreal, 1957). ‖ A. Bauer, *Rock Mechanics—Blasting Characteristics of Frozen Ore and Overburden* (Canadian Industries Ltd., Montreal, 1959). # Measurements by Intermountain Research and Engineering Co., Inc., Salt Lake City, Utah. ¶ Dry basis. ** A. Bauer and M. A. Cook (Institute of Metals and Explosives Research, University of Utah), unpublished. †† Cap sensitive (core only). ‡‡ Blasting cap. §§ Smallest blasting caps.

elimination from the borehole of blasting caps in large-diameter blasting; this was a great advantage from the standpoint of safety, Primacord being relatively much less hazardous than blasting caps, owing to (i) the use of a less sensitive explosive and (ii) the protection afforded the explosive core by the soft, pliable sheath. Moreover, the use of Primacord greatly simplified and facilitated the loading of large, multiple-hole blasts.

"Millisecond-" or "MS-delay" blasting, introduced more than a decade ago with the "Rockmaster" system of the Atlas Powder Company, provided an accurately timed, sequential blasting system. It was based at first on instantaneous caps fired in proper sequence and at appropriate (10- to 30-millisecond) intervals by special delay switching methods. Its early success led later to the development of special millisecond-delay blasting caps and still later to convenient millisecond-delay Primacord "connectors" or relays (see Fig. 2). Millisecond-delay blasting resulted in significant reduction in powder requirements, improved fragmentation, and marked reductions in seismic wave intensities; seismic waves from large blasts may become quite disturbing in surrounding residential and industrial areas when large multiple-hole blasts are fired without the use of the millisecond-delay methods (*12*).

Detonating systems for large, multiple-hole blasting were finally completely streamlined with the introduction in 1956 of a "ridiculously" small (160 gram) cast Pentolite booster (50 percent trinitrotoluene, 50 percent pentaerythratol tetranitrate) in place of the earlier very cumbersome booster systems (*13–15*). Slurry and the prills and oil mixture can be detonated with as little as 40 to 80 grams of cast Pentolite. Moreover, with the 160-gram cast Pentolite booster, one may tolerate appreciable deviations—for example, at least ± 3 percent—from the desired 6 percent of fuel oil in prills and oil, sensitivity usually dropping appreciably as the oil contact drops below 3 or increases above 9 percent. Consequently, this booster, now marketed by Canadian Industries Limited under the trade name "Pento-Mex," proved entirely adequate, much to the amazement of old-timers, and effected savings sometimes of 90 percent or more in booster costs.

The advantages of cast boosters are: (i) superior boostering action, (ii) superior water resistance (actually they are perfectly water-resistant), and (iii) unexcelled safety features, safety being of vital importance in boosters because they are usually the most dangerous elements in a large blast; the only blasting caps needed are attached after the charge has been loaded and the area has been cleared for firing. Unfortunately, only the most sensitive cast explosives, such as Pentolite, detonate with Primacord, at least in the economical (40- to 60-grain/ft) sizes. By taking advantage of this situation and the high *brisance* of Composition B (55.5 to 59 percent of cyclonite or RDX, 40 to 42 percent of TNT, and 1.0 to 4.5 percent of special organic coating agents), the superior "Procore" boosters were developed (*13–15*). The Procore booster comprises a Primacord-insensitive main booster charge and a Primacord-sensitive (protected) inner core of Pentolite or pentaerythratol tetranitrate, which fires the main charge.

Blasting systems based on Procore or "Pento-Mex" boosters in systems of the type illustrated in Fig. 1*c* comprise the most reliable, safest, and cheapest detonator systems for blasting agents in the modern industry.

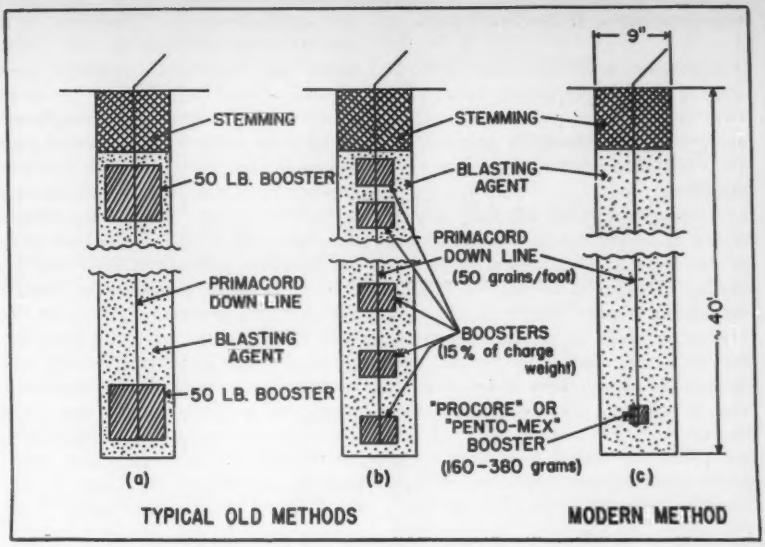


Fig. 1. Diagrams of loaded well-drill holes.

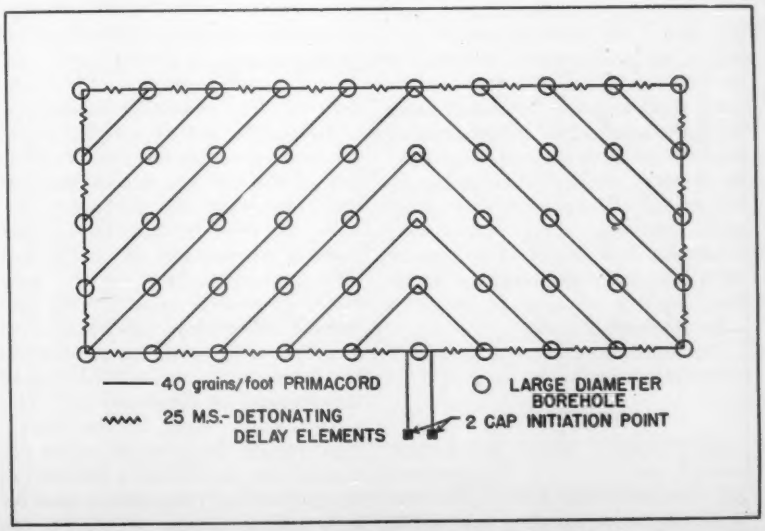


Fig. 2. Typical patterns in multiple-hole blasting.

Characterization of Blasting Agents

Explosive properties important in blasting are (i) detonation velocity D, (ii) "strength," or maximum available energy A, (iii) borehole pressure p_1, (iv) detonation pressure p_2, and (v) sensitivity.

Detonation velocity has long served, in lieu of a more fundamental criterion, as the criterion of intensity of the explosive. Explosives having the highest detonation velocity usually develop the highest *brisance* or shattering action, the property needed in blasting extremely hard rock; those of low detonation velocity are usually nonshattering and adaptable for blasting soft rock and for producing block stone and lump coal. Low-velocity explosives of high strength generally develop good *heaving action*, a term used to imply low but sustained pressure. There are well-known exceptions to these rules; the detonation velocity is merely a useful approximate criterion of the important intensity property of the explosive; it is not always a reliable criterion, especially for widely different types of explosives. Sometimes this is simply because the velocity measured in the laboratory is somewhat different from the real borehole velocity. (The measured velocity D may be much lower than the ideal hydrodynamic or theoretical maximum velocity D^*; moreover, it usually increases relatively rapidly with diameter and confinement, especially in blasting agents.) In other cases the detonation velocity is an unreliable criterion for a more fundamental reason. The more fundamental intensity property characterizing a blasting agent is its borehole pressure p_1—that is, the peak pressure developed in the borehole (*16*). The pressure-time curve of the explosive in borehole blasting is characterized by (i) the intensity property, borehole pressure p_1, and (ii) the extensity property, maximum available energy A. Together, these properties determine, along with loading conditions, how rapidly the pressure drops from the peak pressure p_1 to the final effective pressure p_f where it ceases to do useful work.

The detonation pressure p_2 is defined hydrodynamically by the equation

$$p_2 = \rho_1 DW + p_1 \qquad (1)$$

where ρ_1 is initial density, W is particle velocity, and p_1 is initial pressure (usually completely negligible). The density ρ_2 in the compression part of the detonation wave is 1.25 to 1.4 times the initial density ρ_1. Therefore, p_2 is roughly twice as great as the "adiabatic" or "explosion" pressure p_3—namely, that hypothetical pressure which would be developed by explosion at constant volume and without heat loss to the surroundings. The borehole pressure p_1 is identical to the adiabatic pressure p_3 when the loading density Δ is unity, but when Δ is less than unity the borehole pressure is less than p_3, pressure being very sensitive to density. The borehole pressure p_1 may be defined simply as the adiabatic explosion pressure at the (effective) density $\rho_1\Delta$. With the borehole-pressure concept one allows automatically for free expansion from the volume ρ_1^{-1} per unit mass to the volume $(\rho_1\Delta)^{-1}$ per unit mass, realizing that in free expansion no useful work is done, useful work being accomplished by the explosive only in direct application of pressure against the burden.

Velocity usually varies approximately linearly with density as follows:

$$D \doteq a + b\rho_1 \qquad (2)$$

a and b being constants depending on the explosive and its D/D^* ratio. The approximations $W/D \doteq 1/4$ and $p_3/p_2 \doteq 0.5$ are reliable only within about 20 percent, but a useful approximation at $\Delta = 1.0$ is

$$p_1 = (D^2 - aD^3)/4b \qquad (3)$$

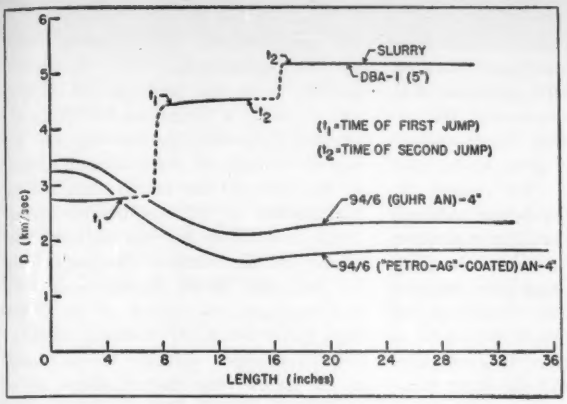
Therefore, only within the limitations of Eq. 3 is the velocity a suitable criterion of the more fundamental borehole pressure, but it is in any event clearly more complicated than a simple linear one in D. The velocity criterion, moreover, does not take proper account of the influence of loading density, Eq. 3 applying only when $\Delta = 1.0$, and even then only as an approximation.

Today, the use of velocity as the criterion expressing the intensity property of the explosive is considered not only ambiguous but unnecessary because the truly fundamental borehole pressure criterion may be applied rapidly, accurately, and reliably upon purely theoretical grounds. For this purpose one employs velocity data, not as a blasting criterion, but in determining the necessary equation of state of the products of detonation (*17*, *18*). Indeed, studies based on the thermohydrodynamic theory of detonation (*1*) have already established a general (although empirical) equation of state for high explosives from which the two main blasting criteria, borehole pressure and strength, may be accurately computed for any explosive without even knowing its detonation velocity (*1*).

Quite aside from a blasting criterion, observations of detonation velocity provide extremely useful information for gauging the performance of an explosive. For instance, one may use variations with diameter of the ratio of observed velocity D to ideal velocity D^* to predict the rate of chemical reaction in detonation (*17*), frequently an important factor in explosive performance. Figure 3 illustrates some velocity transients recorded by a fast electronic oscillograph with prills and oil in 4-inch and slurry in 5-inch unconfined charges, using the "Pento-Mex" booster; knowledge of such transients is of great value in the selection of the appropriate booster and in the design of the blasting agent. Instructive, also are results of modern ultra-high-speed and rotating-mirror framing and "streak" photography of these effects. Figure 4 shows some distance-time results (the slope gives velocity) revealing the influence of different boosters for prills and oil. Note that the *heavy* (400 grain per foot) Primacord boostering of prills and oil is unreliable and inferior; the wave starts out from the Primacord boosters at phenomenally low velocity and picks up only very sluggishly, if at all. In contrast, the "Procore" 3C booster (380 grams) initiates the prills and oil right at its steady-state velocity, without an intervening transient. A striking result shown in Fig. 4 is that the Procore 2A booster, weighing only 160 grams, initiates prills and oil even more effectively than a charge four times larger of the very powerful 75-percent gelatin dynamite.

Modern, ultra-high-speed electronic oscillograph methods have recently been applied to measure detonation velocity in the borehole itself (*19*, *20*). The most valuable result obtained from these studies was the finding that the ratio (D/D^*) of the measured velocity to the ideal one was practically unity in large-diameter boreholes for most of the blasting agents (Table 1). This result negates a great deal of effort that has been expended to increase the ratio D/D^* in prills and oil—for example, by the use of special coatings and careful particle-size control of the ammonium nitrate and by regulation of the oil content, sometimes to as low as 2 percent to achieve the maximum velocity and sensitivity in spite of the adverse effect on strength.

Strength, or maximum available



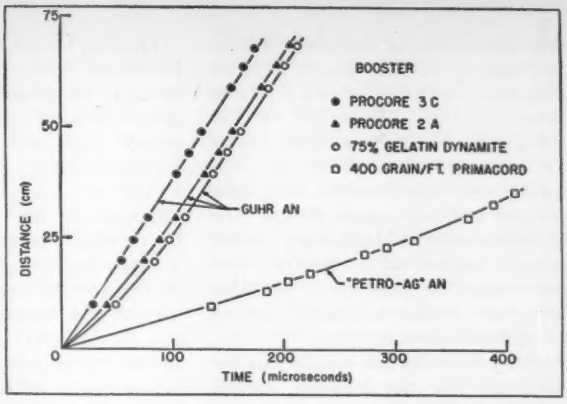


Fig. 3 (left). Velocity transients in unconfined prills and oil (94/6) and slurry with "Pento-Mex" boosters. Fig. 4 (right). Distance-time records in prills and oil (94/6) with different boosters.

energy A, may today be obtained accurately and reliably directly from theoretical computations. It is fundamentally defined by the work integral

$$A = \int_{v_i}^{v_f} p dV \qquad (4)$$

where v_i and v_f are the specific volumes in the initial and final states, respectively. Until recently, experimental methods for measuring strength in blasting agents were lacking, conventional methods for dynamites (the "ballistic mortar" and the "Trauzl block" methods) being not only inapplicable but of very questionable accuracy even for dynamites and of no value for blasting agents. Therefore, the recent development of two field-representative methods for measuring strength represent significant advances in the technology of blasting agents. These are a cratering method (*21*) and a seismic method (*14*). In each, strength A is measured for large charges at unit loading density underground—the condition encountered in practice; in the ballistic mortar one uses only 10 grams of explosive at a loading density of only about 0.04, and in the Trauzl block method the sample size is also only about 10 grams but the loading density is unity. The cratering method developed by Livingston is based on the determination of critical depth for cratering, the crater size as a function of charge weight, and the extent and velocity of "throw-rock," all being related in interesting and enlightening ways in the theory of cratering. Besides providing a measure of the strength A as a basic parameter, the cratering method also yields important information on rock fracture and adaptability of explosives in particular types of rock.

The seismic-strength method relates A to the portion of the total seismic wave energy recorded by the instrument at a fixed distance (preferably about 2500 feet) from charges of appropriate size (preferably about 25 pounds) fired at a fixed depth (usually about 3 feet) in a uniform medium. Appropriate media are water, sand, and uniform alluvium. For good reproducibility in alluvium, a deep, uniform formation should be selected and the same shot hole should be used repeatedly, test shots being fired alternately with calibration shots to eliminate effects of possible changing environmental conditions. For shots in water it is necessary only that the body of water be extensive enough that the banks and bottom do not shatter and undergo change during testing. Loose, fine-grained TNT provides an excellent, reproducible standard for calibration of the seismic-strength system and for reference purposes.

While it may not be obvious that the seismic-strength method is a true measure of strength, one may justify it as follows. (i) The measured total seismic energy varies linearly with the charge weight, as required by any suitable strength method (Fig. 5). (ii) Results do not depend on the density ρ_1 any more than to the extent expected from the theoretical variation of A with density, which is usually negligible, and

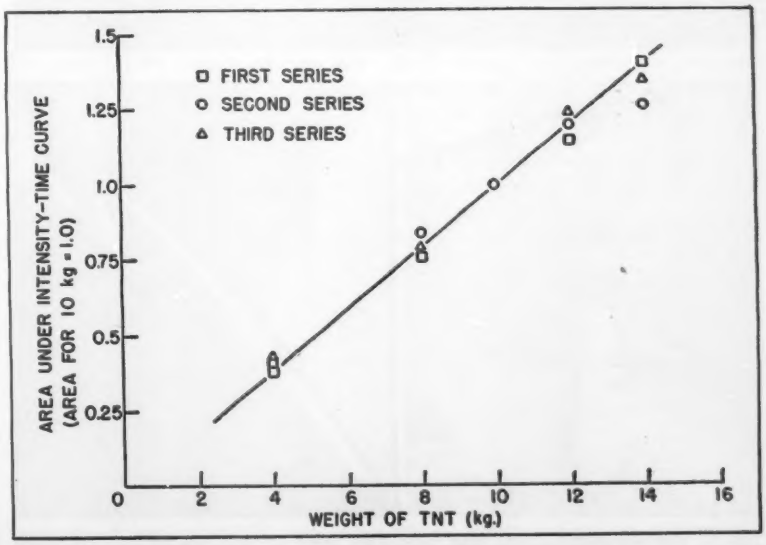


Fig. 5. Measured relative seismic energies for fine TNT at 0.9 gram per cubic centimeter.

they depend not at all on the detonation velocity D. (iii) Results compare favorably with computed relative strengths A/A_0, where A_0 is the strength of the TNT standard (Table 1). (iv) From the theoretical viewpoint it is sufficient to realize that under constant shot-hole conditions the ratio of seismic energy to total energy should remain approximately constant, and that because the geometry is fixed, the instrument records a constant portion of the total seismic energy.

The seismic-strength method has the advantage over the cratering method of relatively low cost and rapid application, but it yields no fundamental information on rock fracture.

Methods for measuring pressure have heretofore been completely lacking, owing to the formidable technical difficulties involved in measuring the extremely high pressures generated by explosives which, in some cases, may exceed 300 kilobars. The recent development of the "aquarium method" for measuring pressures thus represents a major technological advance (*22*). By this method one may now measure not only the detonation pressure p_2 but also high-intensity shock pressures in various media and possibly even borehole pressures, although the latter measurements have not yet been attempted. The aquarium method was recently applied to calibrate the "card-gap" test, the conventional "sensitiveness" test for monopropellants (*23*). In "sensitiveness" tests one measures the critical gap between a donor and a receptor yielding 50 percent detonations and 50 percent failures of the receptor, results in the card-gap test being expressed as the number of 0.25-millimeter plastic cards comprising the gap between the donor and the receptor charges at this 50/50 point. In the aquarium method one measures, by means of an ultra-high-speed streak or framing camera, the initial shock velocity V_w in water as the shock from the explosive, or a medium in question, enters the aquarium (see Fig. 6). The following well-established "impedance mismatch" equation may then be applied to compute, from the measured pressure p_w in water, the actual pressure p_m in the medium in question:

$$p_m = p_w [(\rho V)_w + (\rho V)_m]/2(\rho V)_w \qquad (5)$$

One must, of course, also measure the shock velocity V_m and density ρ of the medium and establish the relationship between the pressure p_w and V_w for water. The necessary calibration curves expressing the pressure-velocity relationship $p(V)$ for water have been established by observing, with the same (back-lighted) aquarium method, the velocity V and "free surface velocity" V_f (V_f is twice the particle velocity U) at the water free surface, with shocks of various intensities ranging from as low as 1 kilobar to above 140 kilobars (Fig. 7). In this method one also makes use of the hydrodynamic equation relating pressure to initial density ρ, shock velocity V, and particle velocity U—namely,

$$p \doteq \rho_1 VU = \rho_1 V\, V_f/2 \qquad (6)$$

Other transparent liquids or solids may also be used to measure pressures in this way; for example, calibration curves have also been established for Lucite, which has been used to measure pressures under conditions where the aquarium method cannot be applied. As a matter of fact, by immersing a charge or device in an aquarium, a high-speed framing camera can be used to establish accurately the pressure contours surrounding an entire charge of explosive or device (see Fig. 8) when the scale factor and framing rate of the camera are known.

Detonation pressure is the most significant property of a booster. For example, one requires only a tenth as

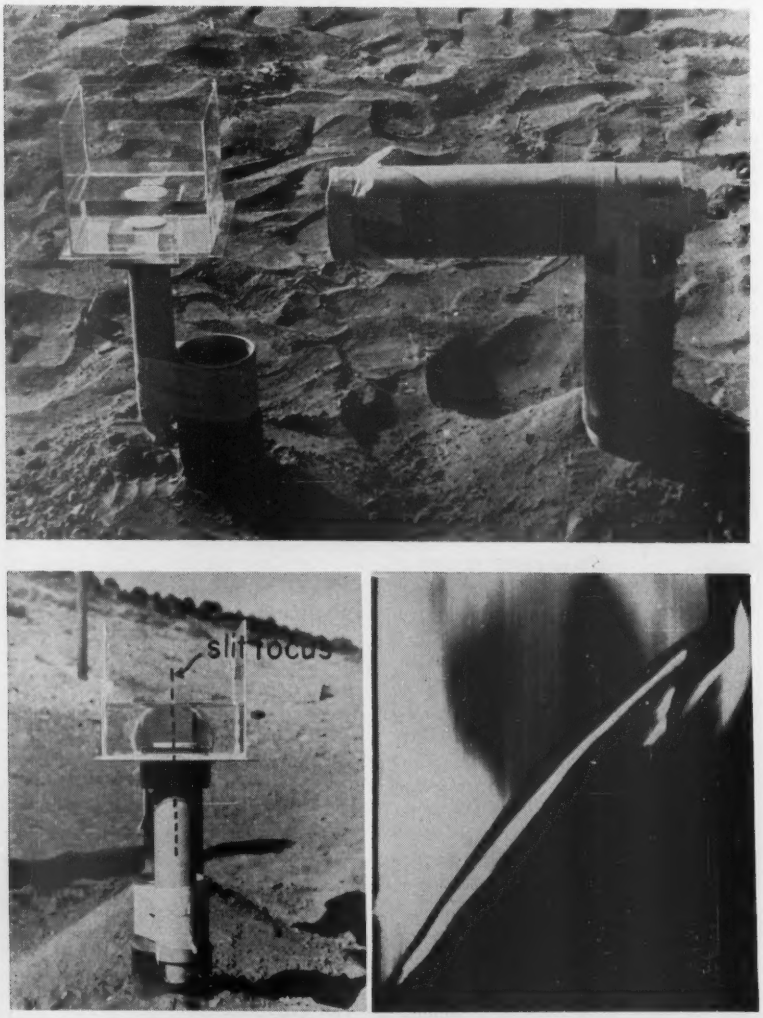


Fig. 6. The aquarium. (Top) Side view; light bomb at right; charge protruding into the aquarium. (Bottom left) End view. (Bottom right) Typical streak camera (time-distance) trace of shock wave in water.

much cast Pentolite (detonation pressure $p_2 = 215$ kbar) as loose TNT of density 0.9 gm/cm^3 ($p_2 = 50$ kbar) and less than 0.25 as much cast Pentolite as 75-percent gelatin dynamite of density 1.4 gm/cm^3 ($p_2 = 135$ kbar) to detonate prills and oil made with kieselguhr-coated, prilled ammonium nitrate. The influence of the detonation pressure is even more important in the boostering of slurry-type blasting agents.

Sensitivity is a vitally important factor in characterizing blasting agents. From a practical viewpoint, performance sensitivity and hazard sensitivity represent two quite different types of sensitivity and, indeed, require quite different experimental methods for their determination, the one measuring the reliability of performance and the other, the relative hazards involved in the formulation, handling, storing, and transportation of the blasting agent. The conventional performance-sensitivity test for dynamites is the air-gap "sensitiveness" test in which one measures the maximum air gap over which detonation will propagate by influence from a 1.25- by 4-inch ("half cartridge test") or a 1.25- by 8-inch ("whole cartridge test") donor to a like receptor. This test is useful in predicting the field performance of dynamites because cartridges may sometimes be separated by air gaps in the borehole. The "drop weight" or "impact" test is a familiar hazard-sensitivity test, suitable, however, only for testing dynamites and other sensitive explosives because only negative results are obtained with less sensitive types. In this test one determines the impact energy for 50 percent detonations and 50 percent failures of about 25 milligrams of explosive placed between small metal cylinders. Friction, heat, and shock sensitivity tests are also available, to evaluate the hazard sensitivity of sensitive explosives, but unfortunately none of these tests is applicable to blasting agents, since only negative results are obtained. It has, therefore, been necessary to establish whole new series of sensitivity tests for blasting agents (*9, 11, 14, 19, 24, 25*).

The applications of blasting agents dictate three types of performance-sensitivity measurements—namely, (i) the critical diameter d_c (the minimum diameter for uniform, consistent propagation), (ii) the minimum booster needed to detonate the blasting agent, and (iii) the large diameter gap "sensitiveness" in which the gap between a donor and receptor is, for example, an aqueous solution (*11*), dirt or other inert substance, or even air—material that might in practice interrupt the continuity of the explosive column. Critical diameter and minimum booster sensitivity tests have been used extensively in recent methods of studying performance sensitivity of blasting agents. The agents may be measured for charges in thin paper tubes six or more charge diameters in length or they may be measured under heavy (for example, steel) confinement. If a blasting agent can be detonated and propagated satisfactorily in a given charge diameter either bare or in a thin paper tube (such charges are referred to as "unconfined"), it will be expected also to perform satisfactorily in the same or larger diameter in the borehole, because the minimum booster requirement and the critical diameter both decrease as the degree of confinement is increased. For example, the unconfined critical diameter d_c and the minimum booster of prills and oil and large-diameter slurry are about 4 inches and 40 grams of cast Pentolite, respectively. On the other hand, these agents can sometimes be propagated in even 2-inch diameter when less than 20 grams of Pentolite are used as the booster. For this reason, to simulate a borehole confinement some prefer to carry out performance-sensitivity measurements in steel pipe (*19, 24*). On the other hand, while the critical diameter measured in pipe is usually considerably less than in a borehole, in one investigation the critical diameters measured for several mixtures of ammonium nitrate and fuel oil in soft ground agreed closely with those measured in unconfined charges but were appreciably greater than those obtained in steel pipe (*6*). This illustrates the danger in reliance upon results obtained under artificial confinement.

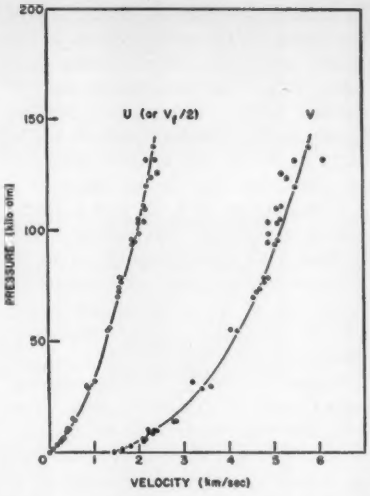


Fig. 7. Calibration $p(V)$ curves for water shock waves (*36*).

Measurements of the minimum booster sensitivity may be based on a uniform series of cast Pentolite boosters of different sizes. Some investigators, however, prefer to use different numbers of blasting caps in a bundle or different numbers of Primacord strips bundled together as the measure of the minimum booster sensitivity (*19, 24, 25*). It is good practice in any case to measure the minimum booster sensitivity in diameters at least 1 inch greater than the critical diameter to avoid confusing results with the ability of the charge to propagate. Also, one should use charges six or more diameters in length to make sure that the explosive actually reaches high-order detonation in a minimum booster sensitivity test.

If one were to rely on the measured critical diameter in unconfined charges as a measure of borehole performance, he would not, of course, attempt to shoot prills and oil in a diameter below 4 inches, irrespective of the type of ammonium nitrate used (*14*). Still, the prills and oil mixture has been shot satisfactorily in boreholes of smaller diameter (usually, however, of short length) by using several periodically spaced boosters. In some instances costly failures have resulted in attempts to use prills and oil in long boreholes 2 to 2.5 inches in diameter. On the other hand, the critical-diameter criterion of performance sensitivity for unconfined charges justifies the use of the more sensitive slurry types (see Table 1, DBA-2) in diameters as small as 1.5 inch, with only one small (1.25- by 1.50-inch) cast Pentolite booster in each hole. Indeed, this blasting agent has been fired satisfactorily in boreholes 1.5-inch in diameter and 150 feet long with but one small Pentolite booster.

The uniformly negative results obtained with blasting agents in conventional hazard-sensitivity tests is dangerous because it has led some to underestimate the hazards. Fuel-sensitized, fertilizer-grade ammonium nitrate is not itself without hazard, as emphasized by the great Texas City

and similar disasters involving ammonium nitrate coated with about 0.75 percent of organic material. Moreover, the prills and oil mixture has actually been observed to explode spontaneously upon standing in large (stemmed) boreholes, owing to chemical incompatibility of prills and oil with certain contaminants which causes self-heating, ignition, and ultimately, spontaneous explosion. Clearly, moreover, the prills and oil mixture is quite as dangerous as dynamite when it is loaded in a truck together with dynamite, as was emphasized by the recent Roseburg, Oregon, disaster.

A novel high-velocity impact test has recently been developed as a positive hazard-sensitivity test for blasting agents (*11*). This test consists of hurling steel plates into charges of blasting agent (9 inches in diameter, 18 inches long) by means of Composition B charges of appropriate size and from a standoff distance of 20 feet. The sensitivity is expressed in terms of the kinetic energy of the impacting plate when 50 percent detonations and 50 percent failures result. For blasting agents, plate velocities should be in the range of 1.8 $\pm$ 0.5 km/sec; appropriate plate sizes fall in the range of 1 inch in diameter by 0.125 inch in thickness to 10 inches in diameter by 1 inch in thickness. This sensitivity is to be compared with that of dynamites, which may be detonated simply by the spit of a blasting cap at comparable stand-off.

Results obtained by the high-velocity impact method (Table 1) thus illustrate the vast superiority of blasting agents over dynamites as regards hazard sensitivity and show strikingly why dynamite tests are inapplicable for blasting agents, and vice versa. For instance, 60- and 75-percent dynamites detonated consistently (or nearly so) at impact energies of less than 0.2 kilocalorie, whereas prills and oil made with kieselguhr-coated ammonium nitrate detonated half the time at an impact kinetic energy of 130 kilocalories. This means that this blasting agent has a hazard sensitivity less than 0.001 that of dynamite (*11*). Another striking result was the fact that prills and oil made with an organic-coated, prilled ammonium nitrate had nine times higher impact sensitivity (15 kilocalories at the 50 percent detonation 50 percent failure point) than prills and oil made with kieselguhr-coated fertilizer-grade ammonium nitrate.

Slurry exhibited phenomenally low impact sensitivity, the large-diameter slurry (DBA-1, Table 1) failing to detonate at all with the exceedingly high impact energy of 2500 kilocalories; even the more sensitive, small-diameter slurry (DBA-2, Table 1) exhibited a 50/50 point of 500 kilocalories.

Illustrative of the great superiority of the cast boosters over the dynamite boosters, the Procore 3C exhibited a 50 percent detonation 50 percent failure point in the high-velocity impact test of 130 kilocalories, the same as for prills and oil made with kieselguhr-coated ammonium nitrate.

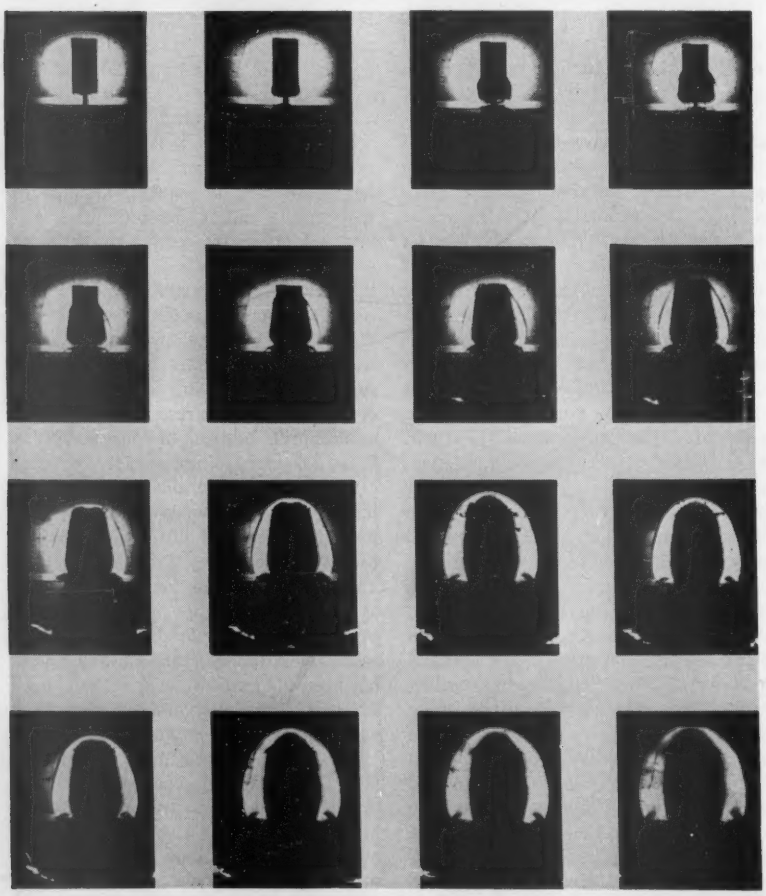


Fig. 8. Megaframe-per-second photographs of a cylindrical charge detonated in the back-lighted aquarium.

Rock Mechanics

Rock mechanics constitutes a vital, but too little investigated, facet of mining research. If the science of rock fracture were sufficiently developed it would be of great value in the operations of drilling, blasting, loading, and crushing of rock. Fortunately, a vigorous world-wide interest in rock mechanics has developed during the past few years, and already many highly beneficial results have been obtained (*21, 26–29*). Million-frame-per-second color photography of wave propagation and fracture in transparent solids has provided striking new fundamental information on the modes and mechanism of fracture of solids in impact loading by detonation and shock waves (*29*). Figure 9 shows such a sequence in Lucite, in which several types of fracture patterns as well as the behavior of interacting shocks are clearly evident.

One has to consider primarily three types of rock fracture: compression, shear, and tensile. Rock breakage is maximized in a blast when the blast is carried out in such a way that the frac-

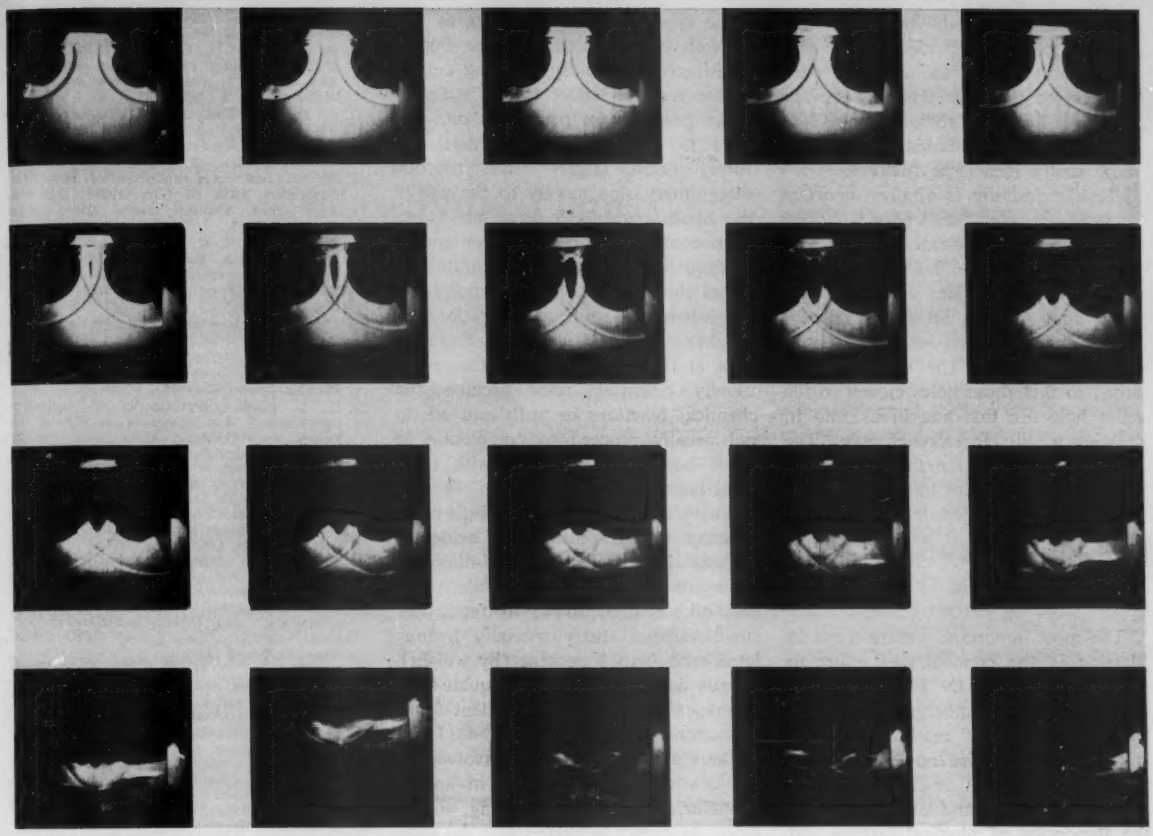


Fig. 9. Megaframe-per-second photographs of shock waves and fragmentation patterns in back-lighted Lucite.

ture is of the type which the rock is least able to resist. Generally, hard rock has very high compressive strength, moderately high shear strength, but relatively low tensile strength. For example, in a typical hard rock the ratios of compressive to shear to tensile strengths may be approximately 100/10/1. One expects, therefore, that the best breakage will occur under conditions where the tensile forces are maximized and the shear and compression forces are minimized. Often a new free face of a well-engineered blast shows a semiborehole in the vicinity of which one observes very little evidence of rock fracture by compression. Since the borehole pressure p_1 is much higher than the compressive strengths of rock recorded in the laboratory, the absence of appreciable compressive fracture in the vicinity of a borehole in a well-engineered blast confirms the belief of many that true compressive strengths of rock are much higher than those indicated by results recorded in the laboratory. Compressive strengths observed in laboratory tests are invariably complicated by artificial, circumstantial shear and tensile fracture incurred by the use of excessively small samples (*30*). Thus, in most hard-rock blasting one generally needs to consider only shear and tensile fracture processes. On the other hand, in the softer, more porous and pliable rock the shear and compressive strengths may be comparable in magnitude to the tensile strength, which then becomes a factor of chief concern.

Because of the usual high shear- to tensile-strength ratio of rock, much more energy is consumed in breaking under shear than under tensile forces. Furthermore, much stronger seismic waves develop, because the intensity of a seismic wave is determined largely by the ultimate strength of the rock (*28*). Herein lies much of the secret of the success of millisecond-delay blasting. In other words, the elimination of shear forces, permitting the rock to break under tension, is no doubt responsible for the appreciable effectiveness of the millisecond-delay blasting.

At least two types of compression waves are generated by the blasting agent: (i) the initial shock wave, which is simply a continuation of the detonation wave, the reflection of which at the free surface produces fragmentation whenever the tension in the reflected tensile wave exceeds the tensile strength of rock, and (ii) a much broader and enduring compression "wave" in which breakage ultimately results either in shear fracture or in what may be called rock bursting, a type of "release-of-load" fracture (*27*). When shear and tensile forces cannot develop, the rock is first compressed and remains under compression for a relatively long time after the initial shock wave has passed, owing to the prolonged application of pressure by the detonation gases. When eventually this compression is relieved as the pressure in the gases drops to a critically low value, the energy stored through compression will usually result in ultimate explosion of the rock. Milli-

second-delay methods have the effect of uncoupling the burden of one shot hole from that of the adjacent ones, so that the desirable tensile wave and release-of-load, or rock-bursting, type fractures may predominate over the more costly shear-type fracture.

Tensile fracture is vitally important in small-diameter "drift rounds." This is perhaps best illustrated by the success of the popular "burn cut" round, in which one provides a sizable open relief hole—that is, an empty hole of 2- to 4-inch diameter—at the center of the burden (*31*). The round is then timed so that those holes closest to the relief hole fire first and break into it, creating a still larger relief hole. The next nearest holes are then fired, and so on until the entire burden has been broken, largely by tensile fracture.

Future Developments

The most important present trend in blasting is the concentrated effort to replace dynamites by blasting agents in small-diameter, underground mining. Problems here are manifold. Dynamites usually require no boosters but merely blasting caps or Primacord fuse to detonate them and are ideal from the standpoint of physical texture and ease of handling, in which respect they will probably never be excelled. But in addition to being extremely hazard-sensitive, both the explosive itself and (usually) its products of detonation are quite toxic. Blasting agents are much more difficult to handle because they require special boosters, have less desirable physical characteristics, and require special loading techniques because of their marginal performance-sensitivities, particularly in small-diameter boreholes. Their great advantages are (i) low cost, (ii) nontoxicity (this may not apply as far as their "fumes" are concerned), and (iii) low hazard sensitivities. Booster requirements of blasting agents for small-diameter use can be met only by careful control of sensitivity, permitting the use of minimum, yet adequate, boosters, because booster costs become critical in small-size charges. Equally difficult is the "fume" problem; the noxious products of detonations, primarily carbon monoxide, the oxides of nitrogen, NH_3, HCN, and so on, may sometimes become very dangerous in underground mining with some types of blasting agents as well as with some dynamites. The Bureau of Mines is currently devoting considerable research effort to the study of fume problems in prills and oil. Results to date (*32*) show that bad fumes result largely from reaction sluggishness, due mainly to the use of the blasting agent in diameters below its unconfined critical diameter and to inadequate boostering. Theoretically, fumes should be excellent in prills and oil when the nitrate-oil ratio (by weight) is 94.5/5.5. Actually, however, even at this ideal ratio the fumes are usually relatively poor because the chemical reactions in prills and oil do not usually proceed to completion in small boreholes, especially with marginal boostering.

Slurry adapted to small-diameter blasting appears attractive, evidently because it has better small-diameter propagation characteristics than prills and oil. Studies show, in fact, that small-diameter slurry specially formulated with 0 to 3 percent (by weight) oxygen deficiency and an adequate performance sensitivity has excellent fume characteristics.

Despite all the problems involved in the use of blasting agents in small-diameter, underground blasting, initial successes justify the belief that the next decade may witness the large-scale replacement of dynamites with the less expensive and much safer blasting agents.

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A Computer Program for Classifying Plants

The computer is programmed to simulate the taxonomic process of comparing each case with every other case.

David J. Rogers and Taffee T. Tanimoto

A complete classification of plants is far from realization. Being well aware that plants form a dynamic, ever-changing group of organisms, no taxonomist ever expects a "complete" system of classification. Nevertheless, the possibility that a thorough, integrated system can and should eventually be produced must not be dismissed.

If no more new areas were to be explored, if no more collections of plants were to be made and stored in the world's herbaria, the number of specimens already on hand would still provide taxonomists with sufficient research material to continue their activity along present lines for at least another 50 years. An even more dismal fact is that plant taxonomists tend to neglect the plants with which we are most intimately associated, the cultivated species.

Stumbling Blocks to Progress

One of the biggest stumbling blocks to more rapid progress is the vast amount of information which must be correlated with great care, even for very small segments of the plant kingdom. Current techniques for comparison of data are largely those used by taxonomists for the past hundred years —that is, comparing, character by character, the specimens, their geographic distribution, and the ecologic and other data of various units (taxa) under study, and slowly accumulating sufficient correlation by "inspection" to allow a satisfactory system of classification. There is no doubt that the taxonomist actually, in his mind, is making comparisons of many variables when he "shuffles" his specimens, but he has been unable to convert his mental picture of these variables into a system which can be communicated readily. Actually, there is no better information retrieval system in use today than that provided by the taxonomist, zoological or botanical.

Many efforts have been made to illustrate, diagram, or reduce to formulas the various pieces of information which are found in plant classification. The most significant of these is the work of Anderson (*1*), whose beautifully simple diagrammatic techniques have been proved valuable in elucidating many problems relating to reduction of masses of data to understandable and workable units. Many efforts have been made to use statistical analyses, but we feel that many systematists have been misled when they have attempted to employ statistical formulas, which in essence measure linear phenomena, for the classification of objects with multitudes of associated variables.

Several recent efforts have been made to correlate a very large number of characteristics (*2–4*). The procedure is to give each of the characteristics equal weight; to derive correlation coefficients and determine the intervals between the correlation coefficients (*4*) which are significant for differentiation of taxa; and finally to set up a classification based on these findings. All these systems have elements which are commendable [the accompanying statements of these workers imply that the systems are closely correlated with "older" orthodox classifications of the same group (*3, 4*)]. If these methods were not so extremely laborious, they might have some chance of ultimate success, but most have been carried to such lengths that they make the process of classification even more difficult than it has been in the past. Further, if analyses were made of the numerous characters utilized in elucidation of an "unweighted" system, it would be found that within a large number of given characters, only certain sets or combinations of characters are actually significant in accomplishing the job of classification. The additional characters may be mere accessories. However, the value of correlating accessory characters with characters of high taxonomic significance, for purposes other than taxonomic, is not to be disregarded.

If one examines the taxonomic methodology, it may be easily seen that in the process employed, even in "classical" taxonomy, numbers of characters are examined, at first unweighted. Then, by a process of elimination, those not useful are dropped. "Weighting" is not a useless procedure in the process of classification. It came to be so considered among certain groups because the taxonomist took the procedure for granted and seldom used specific methods to demonstrate the importance of one character or another. The taxonomist did not feel that it was necessary to demonstrate how a character was weighted. For example, roses have compound leaves; so do some maples. This character is valueless for differentiation of species of roses, all of which have compound leaves, but of value for differentiation of box-elder maple (compound leaves) from other maple species (simple leaves). It has, therefore, a higher order of value or weight for differentiation among the species of maple than it does in the genus *Rosa*.

A Middle Way

If the problems are as outlined above, is there any middle way by which the taxonomist may speed up the process of classification? The classical methods are slow, and statistical methods, frequently too laborious, often do no more than demonstrate the obvious. Can the techniques employed be telescoped? Can the data be gathered, digested, and weighted in some way to assist the botanist and others involved in the problem of data correlation to do their job more rapidly?

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The answer, we think is yes—by the application of the electronic computer to the taxonomic method. The only qualifying comment one should make is that this will not reduce the need for the trained taxonomist. The specialist must know his plants and the discipline of taxonomy as well. It would be foolish to expect a taxonomist to walk into the computer room and start pushing switches intelligently. It would be equally foolish to expect a mathematician to walk into the herbarium and start classifying plants.

If we evaluate normal procedures employed by the taxonomist—the sorting of specimens, the examination of the literature to see how earlier workers have classified the same or similar plant groups, the integration of geographic distribution, the accumulation of genetic and ecological data—and by means of the computer speed up the difficult and slow parts of the process, then the techniques described below may have some value. The program described here simulates the endless process of comparing each case with every other case in order to establish the degree of similarity between the two and thus to sort the cases into natural groupings or clusters for classification. No set judgment of the nature of a species or other taxon is implied. The taxonomic rank to be assigned to the group or cluster must rest finally with the taxonomist.

The computer program has been designed so that the investigator has full control over the process at every stage of comparing and classifying the information. Constant feedback from machine to man permits the fullest play of the subjective judgment of the botanist or other experienced person who understands the implications of the information being processed. The program is flexible enough to permit the investigator to test intuitive impressions or "hunches." It is possible at any time to eliminate a case or an attribute found to be irrelevant and to introduce new data into the system under study whenever the process of classifying indicates new directions which should be explored.

Some species, genera, and perhaps even families are satisfactorily handled by normal taxonomic procedure. Classifications of these by means of a computer would be an obvious waste of time and money. However, for complex taxonomic problems, of which a very large number exist, the computer methods seem ideally suited.

Premachine Operations

It may be helpful to those not familiar with the taxonomist's method of data gathering if we describe it briefly here.

The material used as a case study in the experimental taxonomy computer program consists of 300 herbarium specimens of *Manihot esculenta* (cassava, yuca, manioc, or tapioca) collected by one of us (D. J. R.) (*5*) in Jamaica and Costa Rica. Most specimens represent a separate cultivar, but some duplication exists. Each specimen was selected from a plot in which at least 15 plants of each cultivar were raised under conditions that were nearly identical for the 15 plants. Thus, each specimen is a rough "population sample," taken to represent, as nearly as possible, all the plants of that cultivar.

A habit photograph was made of each specimen at the time of harvesting, at a standard distance against a scaled board, and field notes were made of outstanding characteristics. The form and included information were finally standardized, and with the resulting data sheet it was possible to go directly from field data to punched card.

Choosing the Field Data

The information placed on the standardized form was chosen with specific reference to its usefulness in differentiating the cultivars. Because *Manihot* plants are vegetatively reproduced in culture and because the root produces the food, it is desirable to distinguish the cultivars by vegetative characters, and it is only of secondary importance to know the characteristics of the flower, fruit, and seed. Indeed, we have never observed some of the cultivars in flower, and they may have been so highly selected by those who use the plants for their basic food that flowering seldom occurs.

Additional data taken from the herbarium specimens were added to the standardized form after it was returned to the laboratory. All the data related to gross morphology or to pigmentation. No anatomical or biochemical information was used. Several attempts were made to include findings on the hydrogen cyanide content of the roots and findings from crude protein analyses of the foliage (*6*), but because the sample numbers were confused, it was impossible to correlate these data with all the rest.

Table 1. Characteristics and attributes.

Characteristic	Attribute	Presence
Color of stem	Gray	No
	Brown	Yes
	Yellow	No
	Red	No
Leaf shape	Linear	No
	Obovoid	Yes
	Pandurate	No

Table 2. Characteristics and attributes.

Characteristic	Attribute	Presence
Soil type on which plant grows	Acid sand	No
	Basic clay	No
	Clay and /or sand	Yes
	Volcanic soils	No
	No soil preference	No

Because most cultivars of *Manihot esculenta* occur in South America, particularly in Brazil, no final conclusions on the over-all classification of this variable species are possible. However, studies of the specimens so far collected permit a rough classification.

The computer program has been designed to analyze both qualitative data (that is, data expressed more accurately in yes-or-no form than in terms of numerical values arbitrarily assigned to describe the same qualities) and quantitative data. As an example of qualitative data, with this program it is possible to classify information dealing with "intangible" qualities such as variations in colors of plants.

The first step in preparing data is to determine which characteristics may be distinguishing within the total group and for each such characteristic to select a suitable set of attributes covering the required range of variation. Some of the main principles are illustrated in Table 1.

Clearly, the attributes must be so chosen that they are mutually exclusive (there must be no more than one *yes* per characteristic). Sometimes this re-

Table 3. Characteristics and attributes.

Characteristic	Attribute	Presence
Leaf pubescence	Glabrous	No
	Glaucous	No
	Puberulent	Yes
	Villose	No
	Tomentose	No

Table 4. Characteristics and attributes.

Characteristic	Attribute	Presence
Leaf lobe length	5–10	No
	11–17	No
	18–20	Yes

quires that a combination of attributes be listed as itself an attribute, as in a species which occurs in more than one type of soil (Table 2). To record a *yes* for the attribute "no soil preference," which means that any soil will do for the plant, is quite different from recording neither a *yes* nor a *no* for any attribute in the list, which means simply that no information is available on that attribute and, therefore, that this particular characteristic cannot be evaluated.

Many subtle characteristics will demand the subjective judgment of the botanist as to whether or not an attribute is present. For example, keen observation would be required to score correctly a characteristic such as the pubescence of a leaf (Table 3).

Some information in any system is most correctly stated in numerical form, especially measurement (of leaf length, leaf width, stamen numbers, chromosome counts, and so on). To include such characteristics in the computer processing, it is only necessary to divide or partition the range of values into a suitable set of intervals, which are then designated as separate attributes (Table 4).

Computer Processing

When all the information has been recorded in standardized form for each case, specimen, or sample, it is then punched into I.B.M. cards for computer processing. Within the computer each *yes* is recorded as the value of *one*, while each *no* is recorded as the value of *zero*. In this form, the computer can automatically compare each case with every other case, as shown in Table 5.

Next, the computer counts the number of one's common to both and also counts the total number of distinct attributes (ones) possessed by case 1 and case 2 to arrive at the similarity ratio s_{12} for cases 1 and 2; that is, s_{12} is the ratio of the number of attributes in common in cases 1 and 2 to the number of distinct attributes possessed by cases 1 and 2 (*7*).

If no attributes for the two cases match, the ratio will be zero. If s_{12} is not zero, it will always be less than or equal to one and signifies that case 1 is related to case 2. The ratio s_{12} is one when all of the attributes match; in particular, the similarity ratio of any case with itself is always one. The ratio may be interpreted as the probability of selecting at random an attribute common to both cases 1 and 2 out of all the attributes possessed by them collectively. Hence, a similarity ratio which is nearly one would indicate a great degree of similarity between the two cases. Similarly, a small but nonzero value of the ratio corresponding to a pair of cases would indicate a nonrandom divergence of characteristics.

Table 5. Case comparisons.

Characteristic	A	B	C	D	E
Attribute	a b c d	a b	a b c d e	a b c d	a b c
Case No. 1	0 0 1 0	0 1	0 1 0 0 0	0 1 0 0	0 0 0
Case No. 2	0 1 0 0	0 1	0 0 1 0 0	0 1 0 0	1 0 0
Attributes in common in cases Nos. 1 and 2	0 0 0 0	0 1	0 0 0 0 0	0 1 0 0	0 0 0
Total distinct attributes in cases Nos. 1 and 2	0 1 1 0	0 1	0 1 1 0 0	0 1 0 0	1 0 0

One may define a "distance" d_{ij} between case i and case j by

$$d_{ij} = -\log_2 s_{ij}$$

where s_{ij} is the similarity ratio corresponding to cases i and j, so that if the cases are considered as geometrical points in a suitable space, the symmetric matrix (d_{ij}) is quite analogous to a mileage chart giving the distance between case i and case j. Note that if case i is very similar to case j—that is, if s_{ij} is nearly one, the distance d_{ij} is small, so that case i is very close to case j in a geometrical sense as well as in a qualitative sense. Function d_{ij} defines what is known in mathematics as a semimetric space as contrasted with a metric space, since the sum of two sides of a triangle is not necessarily greater than the third. Designation of a space as semimetric implies that there may be two cases both related to a third in such a way that the first two may not necessarily even be related to each other. However, when a distance function defines a metric space, two cases which are both related to a third will be necessarily directly related to each other. Thus, a semimetric space seems to be more advantageous for our purposes. In terms of information theory (*8*), d_{ij} is the total information in "bits" conveyed by the event of selecting at random an attribute common to case i and case j out of the totality of distinct attributes possessed by cases i and j.

First, assuming all of the distances d_{ij} to be finite, we define an over-all number H_i associated with case i by

$$H_i = \Sigma_j d_{ij} = \Sigma_j -\log_2 s_{ij}$$

That is, H_i is the sum of all of the n-1 distances (if we have n cases) from the case i to all of the other related cases. That case i_0 for which the corresponding value of H_{i_0} is the least,

$$H_{i_0} = \min_i H_i = \min_i \Sigma_j -\log_2 s_{ij}$$

we define as the typical case. Geometrically it is obvious that case i_0, when cases are considered as points, is the point nearest the centroid of the system of points. (This point may not necessarily be unique in certain symmetrical situations.) In terms of probability theory, from the additive-multiplicative property of the logarithmic function, case i_0 is that case which is most likely to have attributes possessed by all of the others; or, in statistical nomenclature, case i_0 is determined by a "maximum likelihood" criterion. From an information-theory point of view, case i_0 possesses the least pairwise over-all total information. (That such a case i_0 is typical has been borne out empirically by a computer program in several applications.)

Before the above over-all analysis is made, the computer places each case in the order of the number of other cases to which it is related. This is done for each case by making a count R_i of the number of other cases with which case i has at least one attribute in common. Suppose that 100 cases are being analyzed, that case 1 has corresponding to it a value $R_1 = 95$, and that all of the other R_i values are less than 95; then case 1 can be considered as being more typical than the others. Thus, for the general situation, using the values R_i and H_i, the computer can rank all of the 100 cases for typicality, first according to their corresponding values R_i of general typicality within the entire collection and then according to their H_i values relative to the other cases having the same R_i

Table 6. "Profile" of typicality.

R value	*H* value	Case No.	Ranking
97	229.0	7	1
97	238.2	68	2
96	221.1	42	3
95	205.9	23	4
95	211.3	88	5
95	213.8	1	6
	etc.		

values. The result is a kind of profile of typicality for the collection as a whole (Table 6).

The case i_0 which ranks first in this typicality table is designated as the prime node, and around it is formed a cluster or a clump of cases very similar to it—that is, cases j, $j = 1,2,\ldots,n$, for which $1 - s_{i_0 j}$ is small.

But how similar to the prime node should another case be in order to qualify for membership in the clump? In order to determine what constitutes a clump, we introduce the notion of a measure of inhomogeneity of a set of cases. We shall say that a set of points form a single uniform clump if the distances between every pair of points are all equal; and if, in addition, the common distance is large, then each point individually can be considered a clump. This is the ideal situation: when all of the similarity ratios corresponding to distinct pairs of the n cases are equal to each other, so that the total entropy $\mathcal{E}_n$ over the system of n points defining $(n/2)(n-1)$ segments can be defined to be

$$\mathcal{E}_n = \log_2 (n/2)(n-1)$$

$\mathcal{E}_n$ is the maximum value that can be attained by an entropy function associated with $(n/2)(n-1)$ segments where the probability of selecting a particular segment is the equally likely geometric probability. In a similar fashion we define the total entropy $E_n[(d_{ij})]$ of a given set of points determined by the cases whose distances are the elements of the matrix (d_{ij}) by

$$E_n[(d_{ij})] = -\tfrac{1}{2}\sum_{ij}{}' \frac{d_{ij}}{T_n\,[(d_{ij})]} \log_2 \frac{d_{ij}}{T_n\,[(d_{ij})]}$$

where the normalization factor is given by

$$T_n[(d_{ij})] = \tfrac{1}{2}\left(\sum_{ij}{}' d_{ij}\right)$$

where $\sum'$ indicates summation only of the finite terms after repeated rows and columns are deleted. If g is the number of zeros in the symmetric matrix (d_{ij}) which lie strictly above the main diagonal, and h is the number of infinite elements above the main diagonal which are not on the same rows and columns as the g zeros, then the maximum entropy expression $\mathcal{E}_n$ must be modified because of degeneracy (that is, points coinciding) and, in addition, the lack of h segments, so that it becomes

$$\mathcal{E}_n(g,h) = \log_2 \left[\frac{n-g}{2}(n-g-1) - h\right]$$

Thus, a reasonable measure of inhomogeneity $u_n[(d_{ij})]$ determined by the matrix (d_{ij}) can be given by the normalized difference

$$u_n\,[(d_{ij})] = \frac{\mathcal{E}_n(g,h) - E_n[(d_{ij})]}{\mathcal{E}_n(g,h)} = 1 - \frac{En[(d_{ij})]}{\mathcal{E}n(g,h)}$$

This expression is identical with Shannon's definition of redundancy (*8*).

At the outset the computer can determine that a homogeneous set of cases constitutes only one clump, or that each individual case is a clump. If u_n is large, that is, near 1), we then, by means of the analysis given above, determine the ranking of typicality.

The computer now considers the cases j, $j = 1, 2, \ldots, n$, for which the distance $d_{i_0 j}$ from the prime node is less than the distance $d_{i_0 j_0}$ from the prime node, to the case j_0 which ranks second in the typicality ranking. If there are k cases within this "open" sphere whose center is the prime node, the computer determines the measure of inhomogeneity u_k of this subset; if u_k is small, the case j_0 which is on the periphery of the sphere is added to the set, and the new inhomogeneity measure u_{k+1} is computed. This process is iterated until the inhomogeneity measure suddenly takes a large jump in value, thus giving us a subset of cases constituting a clump. If u_k is large, the case nearest the periphery of the "open" sphere is removed and the measure of inhomogeneity is recomputed. This process is iterated if necessary. In this case, the worst possible situation is that we have only two members in the first clump, which may be two distinct clumps of a single case each. The prime clump determined in this way is then removed from the collection as a special class to be carefully studied. The machine can also automatically provide an analysis of the attributes in this prime clump, which would be in effect a profile of the differentiating characteristics for the central group of cases.

Similarly, an analysis can be made of attributes for the entire collection, forming a prime cluster of these attributes in the same manner as a prime cluster of cases is selected. This prime cluster of attributes constitutes a profile of the most typical attributes when all cases are considered. It can be compared with the profile of attributes for the special class of cases constituting the prime cluster, to see what significant relationships or divergencies may be revealed.

Likewise, a study can be made of the cases which rank lowest in the typicality scale, to see if a cluster exists there. In the sense of a negation, these least typical cases may reveal important tendencies which might otherwise go unnoticed among the most typical cases at the top of the scale.

Thorough study of all these first results may also lead to valuable conclusions about the usefulness or significance of the information in the original collection, with indications as to which data convey the most information for classification.

In general, prime clusters, being the most typical instances, give the least information about the branching tendencies of natural subgroups within the collection. The next step is to remove these most typical cases or characteristics, or both, from the collection. Then the remainder of the information can be reanalyzed to reveal more specialized clusters of cases and their attendant attributes. This process may be repeated, like the branching of a family tree, until the collection is narrowed down to a residue of only the most *atypical* cases. For example, these atypical cases might represent the nearest approach to the parent species in a hybrid swarm.

At any stage of the processing, the necessary decisions on what direction to take next and whether to terminate the effort can be made by those most able to judge the usefulness of the results up to that moment.

It is clear that this general method of classification, which we might call taxonometrics, can be applied to many areas where many of the data are qualitative (*9*).

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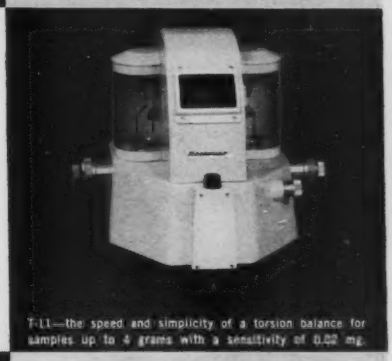

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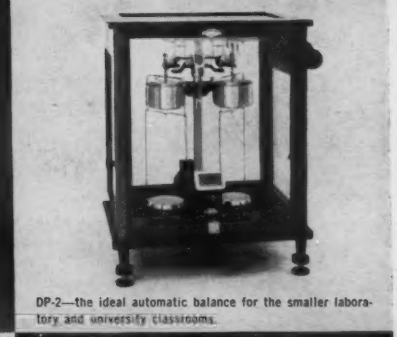

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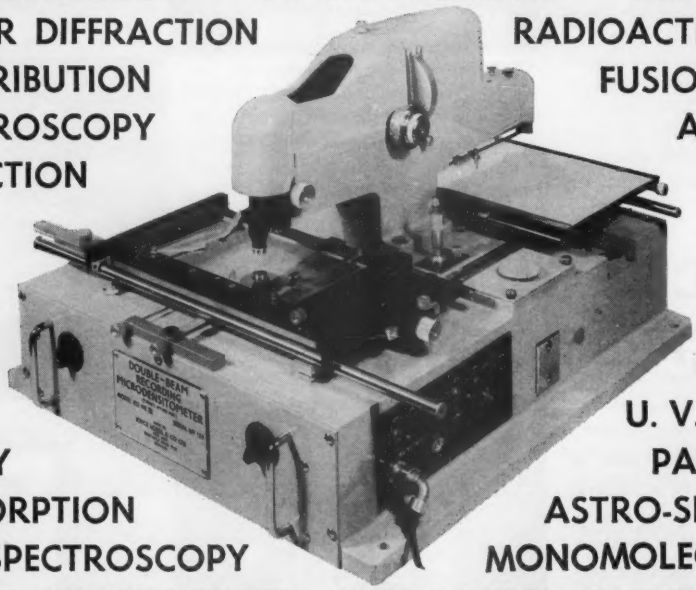

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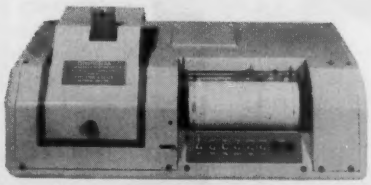

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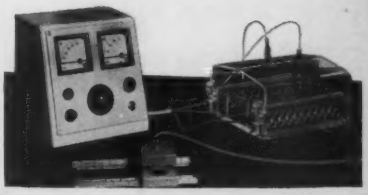

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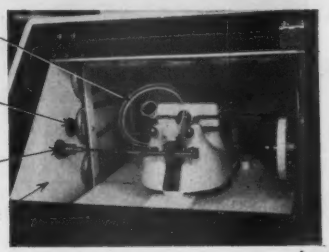

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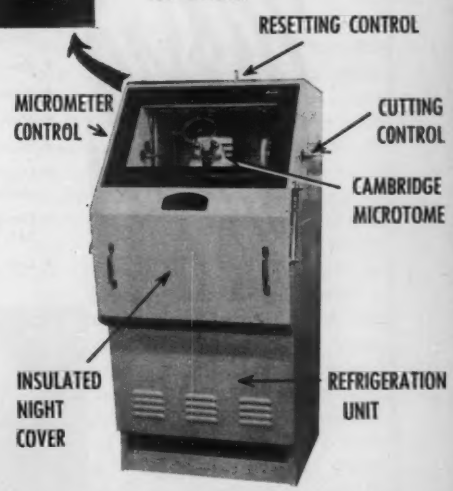

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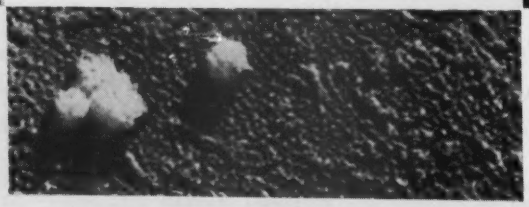

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Photoelectric Photometry in Astronomical Studies

Advances have been made in various fields of astronomy through the use of photoelectric techniques.

Frank Bradshaw Wood

The history of the use of photoelectric techniques in astronomical studies goes back almost to the discovery of the photoelectric effect, but for many years work could be done only on relatively bright objects by persons who were experts in electronics as well as in astronomy. Various factors have changed the picture radically in the past 15 years. The chief of these is the replacement of cells that use gas amplification of the current initially freed at the photosensitive surface by cells that use secondary emission for this purpose. This and other aspects of instrumentation have been dealt with adequately elsewhere. Astronomical photoelectric photometery is some 50 years old, but the facet that concerns us here is that portion of it which might be classified as the modern phase—developments which cover little more than the past ten years. This modern phase is characterized by the use of filters to isolate various regions of the spectrum and by efforts to establish standard color systems; it is characterized by the extension of photoelectric techniques into the infrared region of the spectrum, and by other advances in instrumentation; it is characterized by ingenious spectrophotometric devices in which advantage is taken of the sensitivity and linearity of the photosensitive surface; and, finally, it is characterized by a rapid spread in the number of individuals and institutions that use photoelectric methods, and by worldwide cooperative programs among these.

I shall try to describe briefly the impact of photoelectric photometry upon various fields of modern astronomy; in an article of this length it is, of course, impossible to be all-inclusive.

The author is on the staff of the Flower and Cook Observatory of the University of Pennsylvania, Philadelphia.

Eclipsing Variables

Historically, the first field of stellar astronomy to feel the impact of photoelectric methods was that of eclipsing variables. These are double stars which are much too close together to be seen as anything but a single point of light. In the majority of these systems, the components are even much closer together than the planets of our solar system; in some, the outer envelopes are probably actually in contact. We know that these are double-star systems by the oscillations in the positions of their spectral lines, caused by Doppler displacements as the stars revolve about their common center of gravity, and by the changes in the light caused by successive eclipses as each component passes between us and the other once in each orbital revolution.

A typical "light curve" is shown in Fig. 1. This shows the variation of light with time. When the period has been determined, observations on many nights can be combined to form such a curve, by plotting as abscissa the "phase" or length of time elapsed since the last moment when the greatest loss of light occurred (primary minimum) and as ordinate, the measured difference of magnitude between the variable star and a nearby star of supposedly constant light. In this instance the phase is plotted in terms of the fraction of the period of light variation.

The light changes in this system are caused primarily by two factors. One is the effect of the eclipses as each star alternately passes between us and the other. In this system, the eclipses are nearly equal in depth. This indicates that each star has approximately the same brightness per unit area of its surface and hence that the two components are of nearly the same surface temperature. In systems where one star is much hotter than the other, the hotter component, of course, emits much more radiation per unit area. Since the same area is obscured at each eclipse, in such cases the eclipses are of greatly different depths.

The second main cause of the light changes in this and similar systems is the distortion of each star from spherical form, chiefly by the gravitational attraction of the other. To a rough first approximation, we may say that the stars resemble footballs rather than baseballs, with the long axes pointed toward each other. Thus, near the times of the eclipses we are looking at the smaller ends of the stars, whereas one quarter period later we see much greater areas. In very close systems such as this one, this effect is responsible for a considerable fraction of the total change in light.

Further inspection of the light curve shows that one minimum has a flat bottom, where the light remains constant for an appreciable interval. This shows that this eclipse is total, with the smaller companion behind the larger. A half period later the annular eclipse occurs, and the smaller component passes in front of the larger. We note that the bottom of this eclipse is not flat. The explanation is as follows: If the star were near enough to be seen as a disk, we would notice that it appeared brightest at the center, where our line of sight is perpendicular to the "surface" and thus penetrates more deeply into the star than it does near the edge, where the line of sight is nearly tangential. Since the temperature increases with increasing depth, the star thus appears hottest and brightest at the center—a phenomenon easily observed on the sun. Thus, as the smaller star passes from the edge to the center of the larger, it eclipses successively brighter regions on the surface and loss of light continues, even though the same area is covered at each instant. As it passes from the center to the other edge, the reverse occurs. The exact value of the ratio of the brightness at the edge to that at the center is connected with the process of radiation transfer through the star's atmosphere, and thus it is important to have observational values of this to check predictions made by theory. Yet, with the exception of the sun, no star appears as more than a point of light. Thus, our only observational check (again, apart from the sun) must come from eclipsing systems. Naturally, the more

precise the measures the more precise will be our knowledge of the numerical value of this quantity. The increased precision of photoelectric observations as compared to other techniques is obviously of considerable value here.

This is not the only place in which the increased accuracy of photoelectric observations aids in the study of eclipsing systems. Almost half a century ago Stebbins, using photoelectric methods, and Dugan, using visually a polarizing photometer, independently discovered the so-called reflection effect. This effect, produced by the heating of one side of each star by the radiation of the other, causes the light to be brighter just outside of secondary minimum than it is at a corresponding phase near primary; it also affects in a complicated way the brightness at other portions of the light curve. It must be measured in each individual case before either the ellipticity of the stars or the other elements can be computed.

We have seen how the mere inspection of a light curve can tell us much about a given eclipsing system. Detailed analysis yields much more.

The development by Russell in 1912 of computational methods whereby elements of the system could be derived from the light curve gave impetus to the study of eclipsing stars by photometric methods. Combined with spectrographic results, Russell's methods permit computation of masses, radii, and densities of the components—quantities of fundamental importance to the astronomer. For any given system, the accuracy with which these can be determined will depend upon the precision (and distribution) of the observations; the increased precision made available by photoelectric measures made their use in such studies of particular value.

The astronomer working in this field before 1940 was hampered by two factors. The first was the low sensitivity of the photoelectric cells which limited sharply his choice of stars. The second factor arose from the fact that, while the photosensitive surface itself was reliable in emitting electrons, the means of amplification were by no means so reliable; vacuum techniques had to be used, and the photoelectric photometers of the 1930's and earlier were temperamental instruments. Nevertheless, it was largely (although not entirely) photoelectric observations which showed that the eclipse theory, complex as it is, is not able to explain all the observed phenomena. Even when we allow for effects caused by the nonspherical shapes of the components, by reradiation effects, and by such factors as gravity effects and limb darkening, in many cases we find effects in the light curve which cannot be explained without assuming intrinsic changes in the stars themselves or the presence of great circumstellar streams or shells surrounding one or both of the components.

Sometimes these complications are relatively easy to detect through photoelectric observations, and some have even been detected by methods of lower accuracy. The eclipsing system UX Monocerotis, for example, shows almost continuous erratic fluctuations of light. In some instances the brightness has been observed to increase 15 to 20 percent in less than 15 minutes. Independent photoelectric studies have been carried out at three different observatories, and it is clear that the changes are really changes in the light from the star and are not caused by variations in the transparency of the earth's atmosphere. Intrinsic fluctuations have also been reported for DQ Herculis. This is an old nova which was found by Walker to be also an eclipsing binary. A long list of such systems could be named, ranging from such relatively large variations to changes of the order of 1 or 2 percent in the shape of the light curve. When the variations are this small, it becomes extremely difficult to separate real changes in the star from fluctuations introduced by the earth's atmosphere. Indeed, almost every system which has been observed precisely at different epochs shows some changes which seem to be connected with intrinsic changes of at least one of the components. Careful inspection of Fig. 1, for example, shows that in portions of the light curve the observations on 15, 16, 17, and 18 May do not duplicate precisely those on 30 March and 9–10 April. Even larger changes are shown between this light curve and one obtained of the same system in 1955. Perhaps this is not surprising when we consider the conditions which must exist when two stars are moving around their common center of mass with periods of a few days or even a few hours and with their surfaces separated by a distance which often is only of the order of one stellar radius and frequently is considerably less. To account for such changes, we need new treatment, taking into account the presence of circumstellar material and of disturbances on the stellar photospheres.

In summary, we may say that current photoelectric work on eclipsing stars is characterized by four main developments: the determination, with such precision as is permitted by the atmosphere and by the stars themselves, of the elements of the system; studies of irregularities in the light curves and of sudden changes of period of revolution; the use of narrow band filters to isolate special regions of the spectrum and the extension of observation in the infrared to as far as the 1.6-micron

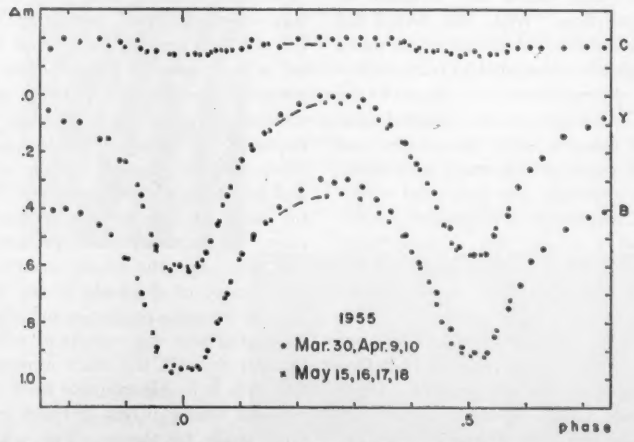


Fig. 1. Light curve of the eclipsing variable AH Virginis. The two lower curves are photoelectric observations in the blue and yellow regions of the spectrum, respectively. They were made by L. Binnendijk at the Flower and Cook Observatory of the University of Pennsylvania. The entire period of light variation is less than 10 hours. The upper curve is the "color curve." This system appears slightly redder at the times of minima than at other parts of the curve. Note that in slightly more than a month, detectable changes occurred in the light curve.

atmospheric window; and international cooperative campaigns in which photometric and spectroscopic observers around the world concentrate for a while on one particular system in an attempt to keep it under extended, continuous observation for a specified interval.

Intrinsic Variables

Studies of intrinsic variables by photoelectric means came later and formerly were less common than work on eclipsing stars, but here too the photoelectric work has had a strong impact on the field. As would be expected, in part its value has been in the detection of details of light and color changes too small or too rapid to be detected by photographic methods. In their authoritative chapter on intrinsic variables in volume 51 of the *Handbuch der Physik*, Ledoux and Walraven remark that perhaps no photometric observations ever made have been used as frequently as the six-color photoelectric observations made by Stebbins and his collaborators on the pulsating stars, δ Cephei, η Aquilae, and RR Lyrae. In a star of this type, the radius alternately increases and decreases as the star expands and contracts in a periodic variation. During contraction the atmosphere becomes hotter because of the compression and hence gives off more light per unit area. It also tends to give off less light because of the decrease in surface area, but this is more than overcome by the temperature effect. During expansion the reverse effects occur. However, simple pulsation of the star as a whole fails entirely to explain many of the observed effects. Modern pulsation theory is extremely complex, making use of such phenomena as shock waves spreading outward through successive layers of the star, but it is still far from successful in explaining all the observed phenomena. Precise observations of light changes, especially the multicolor kind, which take advantage of the relatively long wavelength range over which photoelectric cells are sensitive, frequently bring to light new phenomena to be explained. For example, those of Stebbins and his collaborators showed the maxima arriving at different times in the different wavelength bands. From the light, color, and velocity curves, it is also possible to compute mean radii of these pulsating stars. Other studies have shown differences in the light curves of pulsating variables belonging to different stellar populations and hence presumably of different ages.

Still another use in the study of intrinsic variables lies in the study of stars which show rapid and irregular variations. These fall into various categories. Some, such as AI Velorum or SX Phoenicis, show double or multiple periodicity. An interesting analysis by Walraven of the light curve of the former was possible chiefly because he could follow the variation continuously, using a photoelectric photometer which he had designed for the purpose. In order to study these rapid changes it is necessary to have a continuous record of events rather than the sort of integration provided by photography. SX Phoenicis, for example, on occasion doubles in brightness in less than 20 minutes.

In addition, photoelectric methods are important in studying so-called flare stars of the UV Ceti type. While such stars can be detected by other means (indeed, the variation of UV Ceti itself was first observed by Joy in 1948 on a spectrogram), photoelectric methods are needed to record changes accurately and in detail. In these stars, increases of more than a magnitude take place in 5 minutes or even less. The known stars of this type are late type dwarfs of extremely low luminosity. The rapidity of the changes implies that only a small part of the surface is involved. It has been pointed out that we cannot be certain whether such flares are confined to these stars or whether the low intrinsic brightness of the stars makes the flares more easily detectable than in brighter stars. It would be interesting, although tedious, to follow carefully somewhat brighter dwarfs in the hope of detecting changes similar in form but smaller relative to the star's luminosity.

These are only a few examples of the advances made possible in the study of intrinsic variables by the precision of photoelectric methods and by the fact that, by using appropriate filters, it is possible to observe color changes as well as light changes. In addition to aiding greatly in studies of well-known types of systems, photoelectric techniques have made possible the discovery of hitherto unsuspected types of variable stars—those whose variations of light are very small, so that they may be detected only by the most precise measures. For example, some stars, in addition to other peculiarities, show evidence in their spectra of very strong magnetic fields. In most of these stars the magnetic field varies very rapidly, sometimes in a period of a few days. These variations are accompanied by light variations, and the study of these can be of great importance in determining whether the variation is periodic or irregular and, if periodic, in determining the value of the period. Actually, relatively little photoelectric work has been done to date in this field in comparison with many others, but it is an important one and we may hope for increased activity in the future.

Stars of still another type—the β Cephei or β Canis Majoris variables—show small light changes (and associated spectral changes) occurring in a space of 5 or 6 hours. Some of these changes are periodic; in others, two periods seem to be presented, and the resulting light changes are a beat phenomenon. It would be easy to continue at length, but the preceding paragaphs should show the importance of photoelectric methods in studies of intrinsic variables.

Our Galaxy

In addition to analysis of individual variable stars, we find photoelectric techniques now widely used in studies of the structure of our own galaxy. Our solar system is located within this great assemblage of roughly 100,000 million stars, and the problem of discovering details of the size and structure of the galaxy is a difficult one.

In this work, variable stars again appear, because in addition to being of interest as individual objects they are useful for determinations of distances within our own galaxy and between other galaxies and our own. The distances to globular clusters, for example, are determined chiefly through the study of RR Lyrae variables in these clusters. While there is still discussion as to the precise value, the intrinsic luminosity of these variables is known to a reasonable degree of precision. Thus, by measuring the apparent brightness of these stars, the distances to the clusters can be computed by simple application of the inverse-square law, and the more accurate our observations are, the more precisely are the distances known. The inverse-square law, of course, ignores the fact that some light may have been absorbed by interstellar dust clouds near the plane of the Milky Way, but here again the photoelectric method comes to our aid. Because of the size

of the particles, the blue light from the distant stars is scattered more strongly than the red, and an initially blue or white star will appear red. The observed color of the star can be measured with precision by photoelectric cells and appropriate filters. Since we know the normal colors of the RR Lyrae stars by studies of nearby samples, we can compute the amount of reddening. There is a known relation between this and the total absorption, so that we can allow for the latter and compute the correct distance.

While this method applies to the distant clusters, much of our knowledge of the structure of the Milky Way system in the neighborhood of the sun has come from star counts—that is, counting the number of stars in given areas brighter than a certain apparent magnitude, repeating for one magnitude fainter, and continuing the process. The method goes back to the time of Herschel, but its chief application came from the development of photography and through methods introduced by Kapteyn. One of the chief weaknesses of the photographic method lay in the uncertainties in the magnitude scale. These uncertainties can now be greatly reduced by the establishment of sequences of standard stars whose brightness has been measured photoelectrically. Astronomers in many places are now busy establishing such sequences for various regions. Further, as first shown by W. Becker, measures in three colors allow us to eliminate the reddening effects just described and to determine the true color of the star. Indeed, Stromgren's six-color photometry, with narrow-band interference filters centered in carefully selected critical regions of the spectrum, gives both luminosity and spectral class to a high degree of precision. Thus, while we will probably have to rely on radio waves for studies of more distant portions of the galaxy, photoelectric methods promise a great deal of help in studying details of interstellar material and star distribution in the neighborhood of the sun.

Stellar Evolution

Finally, the precise measurement of magnitudes and colors of stars in clusters has provided important observational evidence concerning stellar evolution. From the measured color-magnitude array (a plot of absolute magnitude or intrinsic luminosity against color) it is actually possible to determine the age of the cluster.

When such a plot is made for the stars in the neighborhood of the sun, most of the stars lie on a band which comprises the familiar "main sequence." This runs progressively from very hot, extremely bright blue stars to very cool, extremely faint red stars. We can measure the amount of radiation from the hot, bright stars and compute the rate at which they are using up their fuel (hydrogen) by converting it into helium plus energy. This rate is very high indeed and for the hotter stars ranges up to many thousands of times the rate at which the sun is exhausting its hydrogen. Yet the masses of these stars, and hence the amounts of fuel available, do not exceed the mass of the sun by anything like this amount. With a very few possible exceptions, 40 times the solar mass is an exceedingly generous estimate for the mass of such a star. Simple arithmetic based on the amount of hydrogen available and the rate at which it is being consumed gives us the upper limit of the age of such a star. In extreme cases this may be of the order of only 10 million years or so. At the end of this time, the hydrogen in the core of the star will have been converted into helium, and changes will begin to take place deep in the interior. It is not in order here to follow in detail these changes and their results upon the visible surface of the star; suffice it to say that the star will evolve rather rapidly and will move from its place on the color-luminosity diagram.

Now we find such stars in the neighborhood of the sun only because the sun is in or near one of the great spiral arms of our galaxy which contains immense clouds of gas and dust. It is from such clouds that the stars must be born. But the globular clusters, for the most part, are singularly free from gas and dust. Thus, it is not surprising now (although it was when the discovery was first made) that, when we plot the color-luminosity diagram of a globular cluster, such bright blue stars are absent.

Detailed computation of stellar interiors, such as those which have been carried out by Schwarzschild and his collaborators, tell us the rate at which a star exhausts the hydrogen in its core. This rate depends on the mass of the star and proceeds very much more rapidly for the more massive stars. For a star of any given mass (and hence, in general, of a known related luminosity) there can be computed the length of time which must elapse before the star in the course of its evolution moves away from the main sequence. When we observe the globular clusters, we find that a large part of the upper main sequence is absent, since the stars originally there have moved elsewhere. Comparison of the observed results with the theoretical computations gives us the age of the cluster. Further, observation of the position on the diagram of the cluster stars which are no longer on the main sequence gives us a clue as to what happens to the stars in the course of their later evolution.

We can apply the same treatment to galactic clusters, but here we get a greater variety of results. One or two show a color-magnitude diagram resembling the globular clusters and thus appear to be of almost the same age. In most of them, however, much less of the upper main sequence is missing; just how much gives us the age of the cluster. In the very youngest, the entire main sequence is present, including the bright blue stars. In these youngest clusters it is the lowest part of the main sequence which does not fall in the normal position. Since the rate of contraction depends on the mass of the star, this finding seems to indicate that these stars of low mass have not yet had time to complete their contraction stage and to attain the combination of radius and surface temperature which they, spending their hydrogen slowly, will have for many billions of years.

Other Applications

This has been a rather brief survey of some of the ways in which the use of photoelectric cells have aided in modern astronomy. Any astronomer reading this will note many omissions. I have not discussed photoelectric measures of either the nearby planets or of the distant external galaxies. Photoelectric cells used as aids in guiding or in measuring photographic plates have not been discussed, nor have photoelectric cells used in conjunction with prisms or gratings. Photoelectric work in the infrared has been omitted, and no attention has been given to the development of image intensifiers and various other developments. Even the topics treated have been treated sketchily. Comprehensive coverage is no longer possible in an article of reasonable length. But before closing I do want to mention one possible develop-

ment of the future which may have considerable impact in the field of eclipsing and intrinsic variables and that is the entry of intelligent and enthusiastic amateur astronomers into the field of photoelectric astronomy.

Amateur Astronomers

For centuries, amateurs have made worth-while contributions to astronomy. Among them have been a few great names such as Herschel, Goodricke, and Lord Rosse and, in addition, a host of other individuals who have spent their free time in making and reporting observations. Today amateurs are organized in groups large and small, and a great many cities have their astronomical units. On the national scale the organizations include the American Association of Variable Star Observers (AAVSO) and the Astronomical League. Such organizations are by no means confined to this country. The Southern Hemisphere has the Royal New Zealand Astronomical Society and the Astronomical Society of Southern Africa, as well as various groups in South America. England has produced active amateur astronomers for centuries and has, like almost every country in Western Europe, organized associations of amateur astronomers.

Further, the contribution of amateurs to the field of variable stars has been particularly great. Some organizations, such as the AAVSO, the New Zealand Society, and the amateurs in Berlin, issue their own publications. In other cases (R. Weber in France and G. Romano in Italy are examples), amateurs publish their discoveries in professional journals. To date, the bulk of such work has been done almost entirely by visual and photographic means. But there is no reason why amateurs cannot now build simple photoelectric photometers and use these with telescopes of moderate size to observe the brighter variable stars. Indeed, the *Publications of the Astronomical Society of the Pacific* have carried light curves of variables observed by an amateur, J. J. Ruiz, with equipment built by himself, and a handful of other amateurs are engaged in taking similar measures. If any appreciable number of amateurs become thus engaged, they can by sheer force of numbers do what all the professional astronomers in the world cannot do—keep under reasonably constant surveillance a considerable number of the more interesting of the brighter variable stars.

Conclusion

In closing I should probably try to predict what studies made with instruments that take advantage of the photoelectric effect may be expected to accomplish in the future, but the potential advances in instrumentation are so wide that it is not possible to predict with any confidence what the most useful applications will be, and a list of possibilities would be unduly long. Perhaps the most obvious field is the development of image intensifiers. Experimental work, which began with Lallemand at Paris and has now spread to several observatories, shows that image intensifiers are indeed practical and that, by greatly increasing the quantum efficiency of the receiver, they can indeed for many (but not all) purposes make large telescopes out of small ones—that is, permit telescopes of very modest aperture to do work which was previously possible only with the larger ones. Scanning devices, such as those developed by McGee at London, may also play their part. Whatever the details, it is certain that much of the future of observational astronomy will be written by astronomers making use of equipment which takes advantage of the photoelectric effect.

Integration of Circuit Functions into Solids

The trend in electronic circuit construction is toward microminiaturization and molecular electronics.

S. W. Herwald and S. J. Angello

The development of electronics has, since the beginning, featured progress in reducing the size and weight of equipment required to perform a given function. Substantial progress was made during World War II with the introduction of miniature and subminiature tubes. Unfortunately, mere reduction in size often leads to problems in component handling and assembly which result in increased costs and in less reliability than is found with the larger circuit function. The problem of reliability has become of such importance that recent developments have put this item ahead of size reduction in the list of objectives.

In this article we discuss the techniques which have been developed over the last decade to accomplish reduction in size and, at the same time, increase reliability, with a future potential for cost reduction. Emphasis is placed on circuit functions in solids, for this technique is in the earliest stage of research and development and shows great potential for the future.

Why Make Circuits Smaller?

One straightforward answer to the question "Why make circuits smaller?" may be found in Fig. 1. The complexity of systems is becoming very great. Pre-1940 electronic techniques will not satisfy the space requirements of the B-58 airplane. Even in ships, where one might imagine there would be no limitation on space, the problem of the size of electronic equipment is receiving attention. Space and weight restric-

Dr. Herwald is vice president for central engineering of the Westinghouse Electric Corporation, Pittsburgh, Pa. Dr. Angello is project manager for molecular electronics of the Westinghouse Air Arm Division, Baltimore, Md.

tions for equipment in missiles and satellites are other obvious reasons for making circuits smaller.

Some more subtle advantages of miniaturization may be cited. For example, in a digital computer of high speed, the time required to propagate a signal through the system can become a limiting factor. It is then necessary to compress circuits and interconnections. The lighter weight which accompanies decreased size tends to enhance the ability of equipment to withstand mechanical shock. With respect to environmental requirements, miniaturization makes hermetic sealing of complete circuits economically possible. Another advantage of hermetically sealed modules, besides protection from the atmosphere, stems from the fact that an enormous number of different circuit functions can be provided inside these modules. The module itself can be subjected to an extensive series of reliability tests—a time-consuming and expensive process. Once carried out, this procedure need not to be repeated in its entirety each time a new circuit is made inside the module. The economies of standardization will show up ultimately in lower costs than for conventional circuits.

One aim of the various miniaturization techniques is reduction in the number of solder-joint interconnections in a system. It is well known that solder joints are reliability hazards. The probability of survival (P) of a system during the course of a mission is the product of the probabilities for survival of the n individual components and connections making up the system: that is,

$$P = P_1 \times P_2 \times \ldots P_i \times \ldots P_n$$

An interesting deduction may be made if we establish the average survival probability of the components and connections by the expression

$$P_{av} = \sum_{i=1}^{n} P_i/n$$

for then the total survival probability for the system is

$$P = \left[\sum_{1}^{n} P_i/n\right]^n$$

In this form it may be seen that more is to be gained by reducing the value of n than by improving the individual probabilities (P_i).

Maintenance is an important problem in the application of electronic systems. Smaller, encapsulated circuits will help in at least two ways. Greater reliability will reduce maintenance, and the compact modules will simplify replacement. As circuit modules become more economical, more complex circuits may be included in the replacement module. This will transfer complex maintenance problems to the manufacturer, who has expert personnel and equipment for this purpose, and field problems may then be handled by relatively inexperienced people.

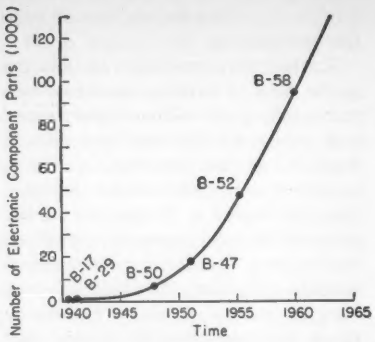


Fig. 1. Trend of complexity of electronics in U.S. Air Force weapon systems.

How To Make Circuits Smaller: The Transistor

It has been pointed out many times in the literature that the thermionic vacuum tube is a very inefficient device for information-handling functions. Whereas microwatts to milliwatts of power are usually sufficient for communication, the filaments of vacuum tubes require tenths of watts solely for the purpose of boiling electrons from the cathode surface. The requirement for such sources of heat within electronic equipment seriously limits the number of parts which can be contained in a unit of volume while still maintaining a safe operating temperature.

In July 1948 the invention of the transistor was announced (*1*). This device has power requirements which are comparable to the signal levels that are being handled. The transistor does not eliminate the problem of power dissipation in electronic circuits, but it does permit an increase in parts density of several orders of magnitude before the temperature rise becomes serious.

Two important developments that followed quickly upon the announcement of the transistor were the *p-n* and *p-n-p* (*2*) junction devices. These developments are the present basis for the integration of circuits into semiconductor substrates. Since the equivalent circuit of a *p-n* junction biased in the high-resistance direction is a capacitor shunted by a high resistance, a three-layer *pnp* (or *npn*) semiconductor substrate provides the essentials to form resistance-capacitance active networks.

Major Approaches to Small Circuits

There are three important approaches to the construction of small circuits. These are: (i) microcomponent assembly; (ii) two-dimensional microminiaturization; and (iii) functional electronic blocks. We shall discuss the first two briefly to establish the historical perspective, then we shall concentrate our attention upon the state of the art and the future problems of the third.

Microcomponent assembly. Microcomponent assembly is exemplified by the Navy "Tinkertoy" project (*3*) and by the Signal Corps "Micromodule" program (*4*).

The first obvious advantage of this approach is the availability of an almost complete range of components from which to plan the construction of systems. If a proper supplier-assembler relationship is set up, cost reductions through mass production should be realized. The interconnection of circuits is combined with the assembly structure, as shown in Fig. 2. Because of light weight and small size, this structure should withstand mechanical shocks. The final structure is resin-embedded to provide environmental protection. No appreciable reduction in numbers of components and soldered joints is achieved by this approach. Danko *et al.* (*4*) give a comprehensive description of the program, with references to pertinent literature.

Other assembly schemes are being used which are similar to the micromodule. Several manufacturers of semiconductor devices are producing microminiature diodes and transistors under standards suggested by the TR 25.1.1 subcommittee on microminiature components of the Electrical Industries Association. Compatible resistors and capacitors are becoming available. Fotoceram boards can be etched with slots and holes to hold the components, and many ingenious interconnection schemes have been devised. These techniques offer solutions to the problem of constructing small equipment with minimum lead time.

An interesting variation of the concept is evidenced in the thermionic

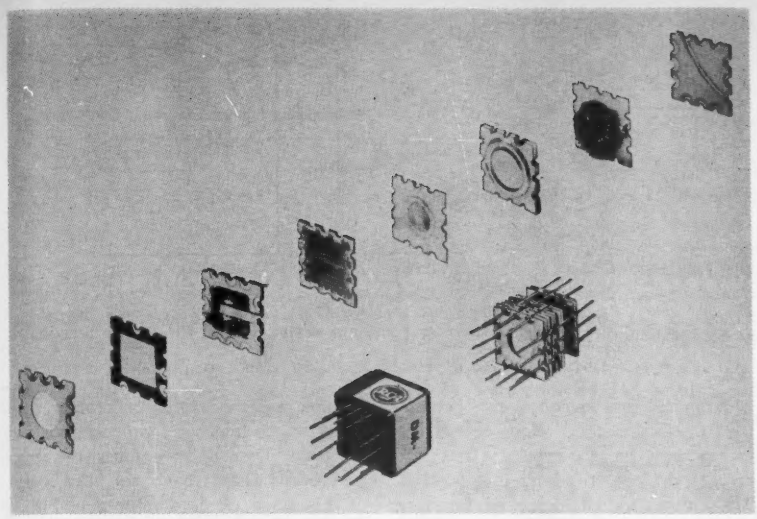


Fig. 2. Exploded view of a typical micromodule. [Radio Corporation of America]

micromodule. This approach consists of building high-temperature resistors and capacitors into the envelopes of all-ceramic thermionic tubes. Devices of this type are especially appropriate for high-temperature (~ 500°C) operation and survival in high-intensity nuclear radiation fields.

Two-dimensional microminiaturization. As the name implies, this scheme endeavors to make the thickness dimension of a circuit vanishingly small —hence, to make the circuit two-dimensional. Such two-dimensional circuits can then be closely stacked to form the three-dimensional equipment module.

All of the classes of schemes mentioned have at least one thing in common; they depend in one way or another upon the mechanical support of a thin wafer. The micromodules use 0.310- by 0.310- by 0.010-inch alumina or Fotoceram wafers, depending upon the components to be supported. Two-dimensional circuits use similar wafers, and functional blocks use silicon, germanium, or other semiconductors, which may or may not be supported by a ceramic wafer. Because of this common feature, it can be seen that, as developments proceed, a mixture of the three techniques is likely, with the mix determined at any given time by factors such as availability, economy, tested and proved reliability, and performance.

In two-dimensional microminiaturization an attempt is made to process resistors, capacitors, and interconnections on a substrate, preferably in the fewest possible manufacturing steps. Thus, metallic resistors may be made by evaporation of Nichrome on alumina substrate, and capacitors may be made by successive evaporations of metal and dielectric. A detailed description of these techniques is given in (*5*).

Some recent developments in deposition of films make this scheme attractive. A process for sputtering thin, adherent tantalum films has been described (*6*) which has several interesting consequences. The tantalum film can be anodized to form one plate and the dielectric of a capacitor. Since the tantalum oxide is very thin, a large capacitance can be obtained in a small area. Tantalum film resistors can be made which are stable both electrically and mechanically and which exhibit excellent properties of adherence to the substrate. Stable films of this type can provide the basis for circuit interconnections on the substrate which are more reliable and easier to make than soldered joints.

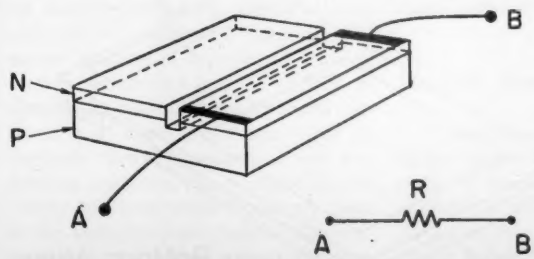
Techniques of this type, coupled with a good scheme of encapsulation (*7*), have potential for use in future systems.

Functional electronic blocks. The integration of circuit functions into solid substrates marks the most recent and advanced approach to the construction of small circuits.

The primary purpose of the functional-block scheme is to rearrange the internal physical properties of a solid to perform a circuit function more complicated than that performed by an individual component. The idea is best described by considering very simple solid structures and then proceeding to more complicated examples. Most of the work so far has centered upon semiconductors, but this is not a necessary restriction. This is a reflection of the fact that semiconductor technology is farther advanced than other pertinent solid-state-device technologies.

Simple Resistance-Capacitance Circuits

We shall illustrate the functional-block scheme by describing how resistors and capacitors can be integrated into a block of *p*-type silicon semiconductor of high resistivity (~ 200 ohm cm). Figure 3 depicts such a *p*-type block with a thin skin of *n*-type, low-resistivity silicon obtained by diffusing antimony into the block. This procedure is a common one for the manufacture of semiconductor devices. Figure 3 also shows a thin slot cut through the skin to isolate a region to which leads have been attached. The region is iso-



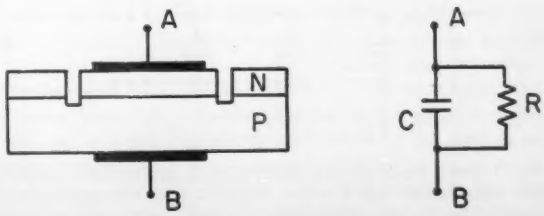
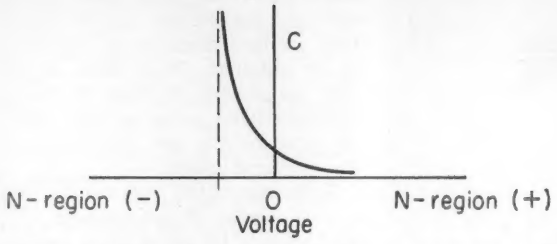


Fig. 3 (left). A silicon block with thin diffused layer. Fig. 4 (right). A diffused silicon block with metallic connections.



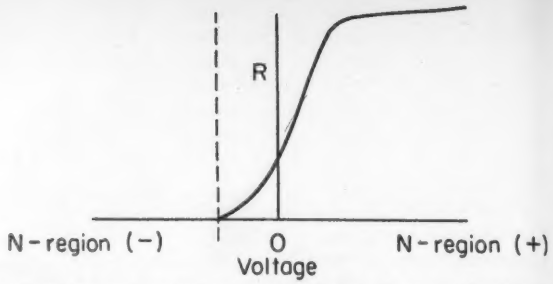


Fig. 5 (left). Capacitance versus voltage for an *n-p* junction. Fig. 6 (right). Leakage resistance versus voltage for an *n-p* junction.

lated because the substrate- to skin-resistivity ratio is greater than 10^5. The slotting operation may be carried out with a fine diamond saw, a scriber, a fine sand blast, or an etch. Etching through Photoresist masks is becoming a common technique. This is the technique developed for surface shaping in two-dimensional microminiaturization. Leads may be attached by furnace fusion, ultrasonic welding, or thermocompression bonding. Other reliable processes are being developed.

A range of resistors may be fabricated on this principle by varying the thickness (by diffusion time, temperature, and type of diffusant), the length, and the width of the *n*-type skin. The range from a few tens of ohms to approximately one megohm may be realized by this method. Ten-percent tolerance can be achieved if trial and error resistance trimming is permitted. The temperature coefficient of resistance follows that for the high-carrier-density diffused skin, which can range from slightly negative, through zero, to slightly positive. Some advantages of this configuration are derived from the intimate connection of the resistor film to the substrate. Silicon is a good heat conductor, and the thermal drop between resistor and substrate is low. Several resistors located on the same substrate will maintain nearly the same temperature as temperature varies over the operating range. Careful designs and appropriate circuits can take advantage of the common temperature to introduce internal compensations for stability. Two disadvantages are that precision resistors have not been made at this stage of development and that very low temperature coefficients have not yet been achieved.

The attachment of metallic areas on each side of the diffused junction (see Fig. 4) results in a capacitor because an *n-p* junction has the equivalent circuit shown in the figure. This capacitance is not constant but varies with applied voltage in the manner illustrated in Fig. 5. At the same time, the resistance across the capacitance varies as shown in Fig. 6. With a few volts positive on the *n*-region, the resistance attains the megohm range, so that a rather good

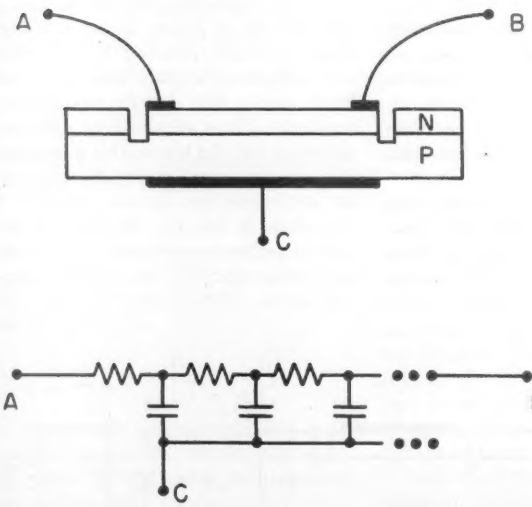
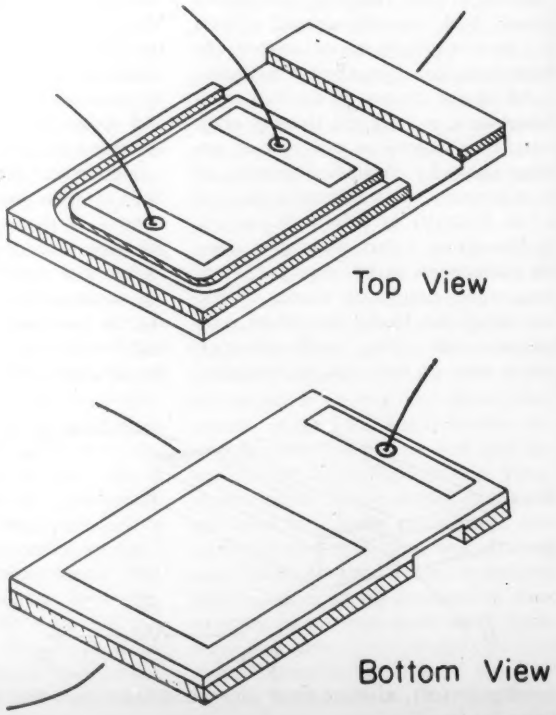
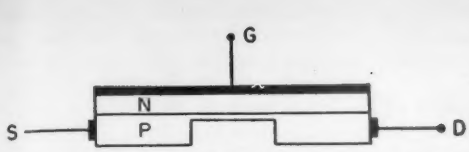


Fig. 7 (left). Phase-shifting network with distributed resistance and capacitance. Fig. 8 (right). A notch filter functional block.





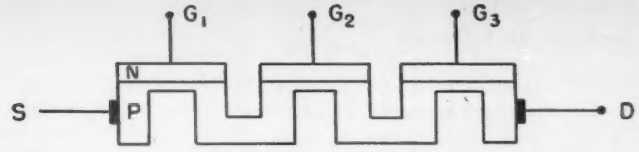


Fig. 9 (left). Basic unipolar transistor configuration. Fig. 10 (right). Example of unipolar transistor logic gate.

capacitor can be obtained under this operating condition. Capacity values are small, being of the order of 0.005 $\mu f/cm^2$. Larger values in the 1 $\mu f/cm^2$ range are more appropriately obtained by two-dimensional techniques, such as the anodized tantalum film. The variation of capacitance with voltage can be useful or a handicap depending upon the application.

An interesting extension of the capacitance block is obtained by combining the configurations of Figs. 3 and 4. Figure 7 illustrates such a configuration, which acts as a phase-shifting network and low pass filter. In this application a deviation from discrete components results because the resistances and capacitances are distributed throughout the block.

Another extension is illustrated in Fig. 8. A resistor, consisting of part of the block, is inserted in series with the metallic condenser plate of Fig. 7. The result is a function block which is frequency-selective, like a bridged-T circuit. Such a narrow frequency band is passed that the term *notch* filter (*8*) is given to this block. This functional block replaces an array of at least nine resistors and condensers, with the soldered joints replaced by internal block configurations. Consequently, only the minimum number of required leads emanate from the block.

Unipolar Transistor Blocks

Another type of functional block which may be fabricated from an *n-p* block depends upon the properties of the unipolar transistor. Figure 9 shows the basic principles. A region of the order of 10^{-4} centimeter thick around an *n-p* junction is depleted of current carriers. When $n(+) - p(-)$ bias is applied, the depletion layer widens and becomes a higher resistance. This is the high reverse resistance of an *n-p* junction diode. In Fig. 9, a cut in the *p*-layer has been made to extend close to the depletion-layer region. This cut should extend deep enough so that under reverse bias the resistance measured between *S* and *D* becomes very high. At zero bias, the *S-D* resistance is relatively low. Thus, a bias on the *n-p* junction acts as a gate to open and close the channel between *S* and *D*.

Some very complex and useful block functions can be invented on the basis of the principle of the unipolar transistor. A simple extension of Fig. 9 can result in a logic gate circuit (*9*). Figure 10 depicts a direct coupled gate. The top slots through the *n*-layer into the *p*-region form resistors between the unipolar transistors. A circuit exists between *S* and *D* if none of the gates are biased. No circuit exists if G_1 or G_2 or G_3 are biased to close the gate.

This discussion has by no means exhausted the possibilities for functional devices to be constructed in an *n-p* silicon block. We point out here (this is discussed more fully below) that progress in the development of functional electronic blocks depends strongly upon the invention of new configurations and construction techniques.

It is clear that one may proceed to develop more complicated functions by adding additional layers to the silicon block. We have seen how two layers provide resistors, capacitors, *n-p* diodes, unipolar transistors, and combinations thereof. Three layers introduce many variations, according to the construction technique. Of course, all of the functions possible with two layers are also possible with three. Adding a fourth layer introduces four-layer switching diodes, trinistors, trigistors, and other varieties of switches with or without control electrodes.

To complete the discussion, we describe below a block involving transistors and one involving switches.

Transistor Block

A basic circuit which may be designed to serve either as a low-level audio, a high-level audio, or a video amplifier is the Darlington connection shown in Fig. 11. The function block shown below the circuit can be constructed as follows. The common collector connections are provided by the metal electrode located on the *p*-region. The input base connection is a metal which forms an *n*-connection with the *n*-region. A *p*-alloy junction to the *n*-region completes the first *pnp* transistor. The second transistor is constructed similarly. Interconnection is effected by allowing the *p*-emitter of the first transistor to fuse at one point to the *n*-base of the second transistor. This illustration is oversimplified in that temperature-compensation resistors and coupling capacitors are omitted. These elements may be included, to result in more stable operation with respect to temperature variations.

A more complicated transistor function block is the bistable multivibrator (*10*) or "flip-flop" block. This type of device contains at least two capacitors, four resistors, and two transistors.

Four-Layer Switch Block

In the discussion so far, the types of function blocks described have had a close analogy with the circuit being replaced. Only a slight deviation from this was noted in the case of distributed resistance-capacitance blocks. It is possible to construct blocks which perform a function having no resemblance to the circuit being replaced. Figure 12 shows a four-layer diode in series with a resistor. Under the sketch is a volt-ampere characteristic. If the load resistance is that shown by the dotted line, the switch will have two stable states, one at high resistance and one at low resistance. A higher load resistance, such as *R*, will permit no stable state, and the circuit will oscillate with a saw-tooth output wave form. Because the load line may be shifted on the characteristic by varying the applied voltage, the relaxation time or output frequency is a function of voltage. This behavior has led to the suggestion that this type of block may be used as an analog-to-digital converter (*11*).

Figure 13 shows several function blocks developed by Westinghouse Electric Corporation for the Air Force.

Future of the Functional Electronic Block Concept

The original studies of function blocks were aimed primarily at reducing the number of interconnections to provide electronic circuits of high reliability and stability against shock. The nature of the concept, however, has led directly to the miniaturization of circuits discussed in this article. Future progress in functional blocks is linked to progress in at least three areas. These are: (i) invention of block configurations; (ii) development of processing techniques for solid-state devices; and (iii) development of new materials.

Invention, Techniques, and Materials

It has been pointed out above that invention is important for progress in functional blocks. To construct analog blocks which follow circuit configurations is possible and useful; however, the aim of simplification will not be furthered in this manner. Not only are new types of block configurations needed but enhanced usefulness of blocks already known is also desirable. Interactions among components on a block can be troublesome, but ingenuity can turn some of these interactions to advantage.

Perhaps one of the most serious limitations of miniaturization is the problem of heat dissipation. Designs of blocks to perform a given function with lower power dissipation is one approach. Better schemes to remove heat is another. Many facets of design enter into the dissipation problem—the tolerance of resistors, for example. The looser the tolerance prescribed in a given circuit, the higher the power dissipation that one can expect. The ideal is to design circuits which may tolerate reasonable spreads in component characteristics and at the same time operate at low power.

More investigation of circuits in the general area of resistance-capacitance active networks is needed if the full potential for two-dimensional miniaturization is to be realized. Circuits containing inductances are usually large and they must be eliminated insofar as possible.

We also need to construct functional blocks with other than semiconductor substrates. Magnetic films, titanate substrates, ferroelectric materials, electroluminescent cells, and Hall generators are fruitful possibilities for the construction of function blocks.

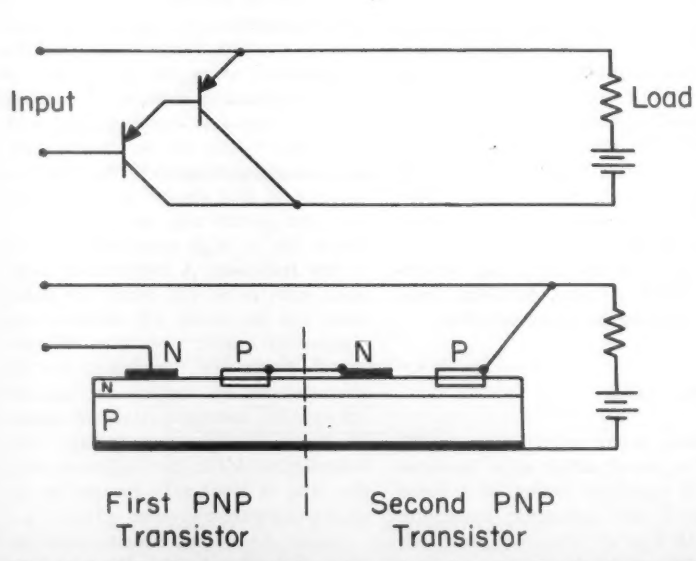
Solid-state devices are also contributing to microwave technique through the various masers, parametric amplifiers, and distributed-line devices. More may be expected in this area.

Construction of a function block, once it has been designed, depends of course upon our ability to fabricate the junctions, slots, holes, and so on needed to perform the function. Another important consideration is that one should aim not to make just one good block but to make a number with acceptable economical yield. This subject is discussed in more detail in (*9*).

More development work is needed in the techniques of masking, etching, electron-beam cutting, and other block-shaping techniques. In this area, two-dimensional microminiaturization and fabrication of function blocks have much in common. One scheme can supplement the other. More development is needed in thin film deposition of capacitors. Refinement of circuit and block interconnections to give reliable and economical use of these techniques will speed their adoption by the electronics industry.

The importance of construction techniques is emphasized by the invention of a four-layer device which is a transistor with two hook collectors (*12*). This device can be operated as a full adder and would be a significant computer function block if it could be constructed with consistent reproducibility. At the present state of the art, the required tolerances cannot be maintained consistently with economical yield. Other instances of need for precise process control will undoubtedly arise as the field develops.

The materials problem has at least two major aspects: (i) New semiconductor materials with new properties are needed to make new functions possible; (ii) improved techniques for



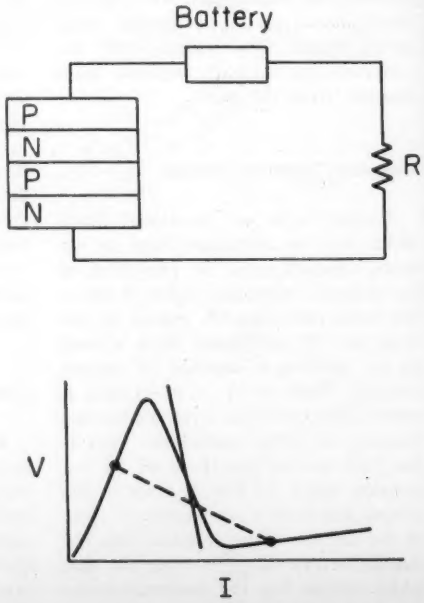


Fig. 11 (left). Darlington connection of transistors in a function block. Fig. 12 (right). A four-layer diode oscillator.

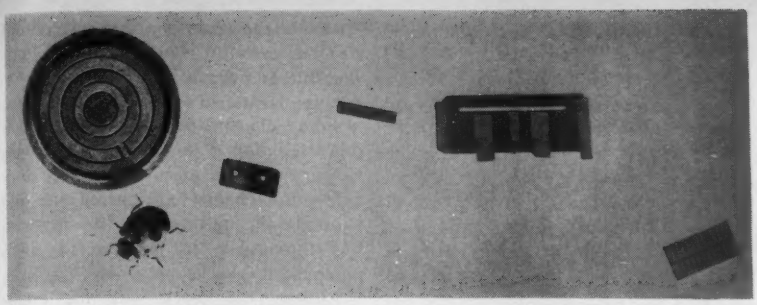


Fig. 13. A photograph of some Westinghouse functional electronic blocks.

handling present materials are required.

Two recent advances in materials modification are discussed here as showing the way to major future advances in function block development. One is the growth of germanium and silicon crystals in dendrite form (*13*). In semiconductor manufacturing practice it is necessary to cut thin wafers from large silicon boules. The process is wasteful of material because the saw is usually of nearly the same thickness as the slice. In addition, the surface layers of the wafer must be removed by etching to eliminate defects introduced by the cutting. Dendrites can be grown from the melt with optically flat surfaces. Proper control will result in ribbons of the width and thickness required for device fabrication. Since the surface of the dendrite as it is pulled is clean and undamaged, further processing can begin without intermediate surface preparations.

The second advance is the growth of epitaxial layers of silicon on a silicon substrate (*14*). By this means, the multiple junction layers required by the function block design may be provided. Earlier in this article functional blocks were described as having two, three, and four layers of various conductivity types. These layers are provided by crystal-growing and impurity-diffusion techniques. Unfortunately, these techniques do not provide the versatility needed to form an arbitrary number of layers with arbitrary electrical conductivities. Epitaxial growth provides this needed versatility and will make possible the construction of functional blocks which cannot be made by the older techniques.

Conclusion

The developments in microcircuitry discussed in this article are the beginnings of profound changes due to take place in electronics. The trend will be away from individual component circuits and toward the integration of circuit functions into functional blocks. The ever-increasing need for reliability will force the development of more reliable assemblies. Functional electronic blocks and two-dimensional techniques in combination will fill this need.

Size and weight are becoming more important in a wider and wider range of applications. Again, integration of components into functional blocks must be carried out to achieve the necessary reduction.

The boundaries between materials and devices and between devices and circuits are being removed, and we shall see an integration of disciplines in the future development of molecular electronics (*15*).

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15. In this rapidly developing field there is no standardized terminology. For example, the subject of this article has been called "solid circuits," "semiconductor networks," and "integrated circuits," as well as molecular electronics.

Photographic Tracking of Elementary Particles

Sheets of emulsion can be stacked so that the tracks of particles can be recorded in three dimensions.

C. F. Powell

In the development of nuclear physics, a decisive role has been played by two principal types of instruments for detecting charged particles and making manifest the tracks that they produce in passing through matter—the counters and the track recorders. It is with the second of these two types of devices that I am here concerned.

The original instrument of this kind was developed by my old teacher, C. T. R. Wilson. In the period from 1900 to 1910 he was able to show that the passage of a charged particle through a gas saturated with water vapor could be made manifest by suddenly expanding the gas immediately before, or immediately after, the passage of the particle. As a result of the expansion, the air tends to become supersaturated, and in suitable conditions the water vapor condenses as small droplets on the individual charged ions and electrons produced in the gas by the particles passing through it.

The great advantage of the Wilson expansion chamber was that it gave a detailed picture of the ionization due to individual particles; in favorable conditions each particle wrote, as it were, its own signature, and ambiguities in the interpretation of phenomena were thereby greatly reduced.

Before the successful development of the Wilson chamber, many features of the interactions between atomic nuclei, and of the processes involved in the ionization of a gas by different radiations, had been inferred from a wide range of experiments with other devices. But with the Wilson chamber these processes were made immediately apparent in all their richness and variety.

To a generation which remembered the tone of the science of 40 years earlier, when it had seemed to many of the most eminent scientists of the day that it was improbable that we should ever be able to penetrate into the structure of atoms—and to some of whom the very idea of atoms appeared as no more than a convenient fiction—the Wilson photographs were an almost magical revelation of a new world. Wilson's pictures of the ionization of a gas by x-rays and, somewhat later, Blackett's photographs of the collisions of alpha particles with nuclei, and the disintegrations that they produced, gave a final demonstration of incomparable clarity that carried overwhelming conviction.

Fully Automatic Chamber

To obtain Wilson photographs of rare events, it was necessary, in some experiments, to make operation of the chamber automatic. Thus, the cross section for the collision of alpha particles with atomic nuclei is so small that there is a probability of only a few parts in a million that such a particle in passing through a gas will make a collision before reaching the end of its range. To demonstrate the disintegration of nitrogen by alpha particles, Blackett and his colleagues developed the fully automatic Wilson chamber, whereby the arduous experiments involved in photographing the tracks in the necessary numbers could be successfully undertaken. Later, Blackett and Occhialini developed the counter-controlled Wilson chamber, whereby charged particles due to cosmic radiation, in passing through Geiger counters disposed above and below the chamber, triggered its expansion; the passage of the particle was thus made to produce its own photograph.

Although in work with the great accelerators the Wilson chamber has now been replaced by bubble chambers, largely because they can operate with liquid hydrogen, many of the basic mechanical features developed in the automatic and counter-controlled Wilson chamber are embodied in the operation of the new instruments. And the power of the Wilson chamber to resolve the finest details of the ionization process has never been equalled in other instruments.

Use of Emulsions

The Wilson expansion chamber has the disadvantage that it is able to record tracks—under the conditions commonly employed—for only about 1/50 second. Since the resetting of the chamber takes about 1 minute, the fraction of the operating time usefully employed is very small. This feature of the Wilson chamber led to a consideration of the possibility of using photographic emulsions for recording tracks directly, since they would have the advantage of being continuously sensitive for long periods. An emulsion consists of myriads of microcrystals of silver halide embedded in gelatine. It was thought that the passage of a charged particle would cause some of those microcrystals penetrated to become developable, so that under the microscope the track in the processed emulsion would appear as a chain of black grains of developed silver, like black beads on an invisible thread.

The early experiments, including those of Walmsley and Makower, and of Kinoshita working in Rutherford's laboratory in Manchester, in the period 1909 to 1914, showed that it was indeed possible to record the tracks of alpha particles in some of the photographic emulsions commercially available at the time. The numbers of grains in the tracks were, however, small, and the tracks were therefore extremely tenuous.

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Early Disadvantages

In the early emulsions, the volume occupied by the silver halide crystals was only about one-eighth that of the surrounding gelatine in which they were embedded. As a result, the individual grains in the track of an alpha particle were widely separated, and the true beginning and end of a track were correspondingly uncertain. Further, the tracks of electrons and other weakly ionizing particles could not be distinguished in the available emulsions, so that the recorded phenomena compared unfavorably with the effects produced by similar processes in a Wilson chamber. And finally, the thickness of the emulsion commonly available was less than 1/20 millimeter, so that fast particles originating in the emulsion frequently escaped from it before reaching the end of their range. Their tracks were therefore incomplete.

As a result of the deficiencies of the early emulsions, the method was little regarded for more than 20 years. In the early 1930's, however, Blau and Wambacker returned to a consideration of the use of emulsions and showed that the tracks of protons as well as of alpha particles could be recorded in some commercial emulsions. They made experiments with protons recoiling from impact by fast neutrons, and with protons emitted from nuclear disintegrations produced by fast alpha particles from radioactive substances. In these experiments, also, however, the difficulty was that the apparent length of the observed tracks gave an imprecise measure of the true range of a particle and, therefore, of its initial energy. Later, Blau and her colleagues showed that it was possible to record also the tracks due to disintegrations produced at mountain altitudes by particles of the cosmic radiation.

Early Experiments in Bristol

My colleagues and I in Bristol became interested in the method during 1938. We had constructed a Cockcroft generator that gave protons of energy about 700 kev, and we had proposed to make experiments with the fast homogeneous groups of neutrons which are generated by the impact of fast protons on light elements such as lithium, beryllium, and boron. The original intention was to use a Wilson chamber to detect the "knock-on" protons projected by the neutrons, but W. Heitler, who was then working in Bristol, directed our attention to Blau's studies of cosmic radiation with photographic plates. We then made an experiment on the Jungfraujoch with a number of plates exposed under different thicknesses of lead, in an attempt to measure the rate of absorption of that component of the cosmic radiation which gave rise to the observed "stars," as the nuclear disintegrations were called.

These experiments on cosmic radiation made us familiar with the elementary features of the photographic method, and we decided to use it in place of a Wilson chamber to try to detect the protons projected by fast neutrons. Using Ilford "half-tone" plates, we found that after about an hour's exposure of a plate with a superficial area of 2 square centimeters, the emulsion being one 30th of a millimeter thick, we were able, after developing the plate, to measure under the microscope hundreds of tracks due to proton recoil in the course of a few hours. The energy spectrum of the neutrons, thus determined in a day or two, was superior in precision to that obtained in the course of about six months' work in experiments with the Wilson chamber. It was evident that for such experiments the photographic method had a number of important advantages.

At the time of these experiments, we were very poorly acquainted with the literature on the subject. In a sense I think this was an advantage, for had we known of all the early unsuccessful experiments to determine the "energy spectra" of charged particles, we might have been discouraged from making a new attempt. In fact, we were fortunate, for the early emulsions, produced for quite different purposes, were not uniform in their performance in recording tracks, and the importance of fading of the latent image and of proper conditions of storage were not appreciated at the time. By chance, the first plates we employed were of relatively high sensitivity. A second circumstance from which we benefited was that, unlike the earlier workers who had employed relatively weak radioactive sources to produce the disintegrations, we had homogeneous beams of relatively great intensity, and we were thus able to demonstrate conclusively some of the most important advantages of the method.

Technical Innovation

By 1945, when World War II ended, a modest field of study in nuclear physics for the photographic emulsion had been established, but it was still limited by the poor quality of the tracks. Attempts had been made to increase the sensitivity of the emulsion and the proportion of silver bromide to gelatine within it, but with little success. But, in 1945, through a technical innovation in manufacturing methods, Dodd and Waller of Ilford Ltd., London, were able to produce emulsions in which the proportion of halide to gelatine was increased over the usual values approximately eightfold, and at about the same time Demers, in Canada, achieved a similar result in his own laboratory.

The advantages of the concentrated emulsions were immediately apparent. The tracks of alpha particles from radioactive substances took the form of almost solid rods of developed grains, and even with less strongly ionizing particles, like fast protons, the tracks were clearly apparent. These developments improved the standing of the photographic method and the precision of the measurements which could be made with it, but it was not until new experiments with cosmic radiation were made that the full potentialities of the method were realized.

In 1945, in collaboration with Occhialini, who had just returned to Bristol from Brazil, we made exposures of the new emulsions at the Pic du Midi in the Pyrenees, and Perkins at the Imperial College, London, made similar experiments on the Jungfraujoch. When the plates were developed and examined under the microscope, it was immediately apparent that a new range of phenomena had been made manifest.

Disintegration of Nuclei

One of the earliest discoveries, made independently by Perkins and by us in Bristol, was that of the disintegration of nuclei by particles after they had reached the end of their range in emulsion. The mass of these particles could be estimated from the characteristics of their tracks and was found to be between 200 and 300 times that of the electron. They were at first thought to be negative mu mesons, discovered in the period 1936 to 1938

by Anderson and Neddermeyer, but almost immediately afterwards examples were found in Bristol of the so-called pi-mu decay.

It was soon shown that a new elementary particle, the pi meson, had been discovered, which could exist in either positively or negatively charged form. The positive particles, when they are brought to rest in matter, cannot approach nuclei because of the repulsion between positive particles. They remain free and decay with a mean lifetime of about 2.6×10^{-8} second. On the other hand, the negative particles are attracted to nuclei, with which they interact, the energy corresponding to their rest-mass being supplied to produce the disintegration of the capturing nucleus.

The discovery of the pi meson illustrated a number of features of the photographic method which were of central importance for its application in the discoveries of new types of elementary particles in the ten years that followed. First, the continuous sensitivity of the emulsion permits rare phenomena to be recorded in exposures of long duration. Second, the observation of the phenomena is so close and intimate that a single example of a new process has frequently permitted correct assessment of its significance, and a few examples have commonly provided decisive evidence. Third, the emulsion is a solid with a density approximately 2000 times greater than that of a gas at normal pressure and temperature. As a consequence, a particle with a given energy is brought to rest in an emulsion after a length of path, and in a period of time, about 2000 times shorter than in a Wilson chamber. It follows that particles with mean lifetimes in the interval from 10^{-8} to 10^{-10} second, when created in nuclear disintegrations in an emulsion, are commonly arrested in it before decaying, whereas in a gas they almost invariably decay while still in motion.

There are important advantages in studying the decay of particles at rest, for the vector sum of the momenta of the secondary particles must then be zero. On the other hand, when, as in a gas, particles decay in flight, it is necessary to know the momentum of a primary particle at the instant of its decay if the principle of the conservation of momentum is to be applied to the analysis of the transformation.

In the ten years that followed the discovery of the pi meson, the photographic method was widely applied both in studies of nuclear disintegrations produced by particles of the cosmic radiation and in investigations with the intense controlled beams of particles produced by the great accelerators as they came into operation.

The method was found to be particularly appropriate for studying cosmic rays with balloons, for it is only necessary to support the emulsions at great altitude for a given period and subsequently to recover the material for development and examination under the microscope. There is, therefore, a complete absence of any complications associated with the use of auxiliary apparatus. And for such work, the continuous sensitivity is a decisive advantage. The most important discoveries about elementary particles made with the photographic method in the period from 1947 to 1959 are included in Table 1.

Many of the discoveries referred to in Table 1 were greatly assisted by two important technical advances—first, by the production of more sensitive emulsions, which were able to give a clear track for even the most weakly ionizing particles known to us, such as fast electrons, and second, by the production of emulsions much thicker than those of conventional photographic plates, and without glass support.

Table 1. Instruments used in the discovery of various elementary particles.

Particle	Source of radiation	Specific behavior or measurement	Instrument used for detection
e^-	Discharge tube	Ratio e/m	Fluorescent screen
e^+	Cosmic rays	Ratio e/m	Wilson cloud chamber
μ^+ μ^-	Cosmic rays	Absence of radiation loss in passage through Pb (also decay at rest)	Wilson cloud chamber
π^+	Cosmic rays	π-μ decay at rest	Nuclear emulsion
π^-	Cosmic rays	Nuclear interaction at rest	Nuclear emulsion
π^0	Accelerator	Decay into γ rays	Counters
K^+	Cosmic rays	$K_{\pi 3}$ decay	Nuclear emulsion
K^-	Cosmic rays	Nuclear interaction at rest	Nuclear emulsion
K^0	Cosmic rays	Decay into $\pi^+ + \pi^-$ in flight	Wilson cloud chamber
n	Polonium plus beryllium	Mass determination from elastic collisions	Ionization chamber
$\bar{p}$	Accelerator	Measurement of e/m plus detection of annihilation	Counters
$\bar{n}$	Accelerator	Detection of annihilation	Counters
Λ^0	Cosmic rays	Decay in flight into $p^+ + \pi^-$	Wilson cloud chamber
$\bar{\Lambda}^0$	Accelerator	Decay in flight into $\bar{p} + \pi^+$	Nuclear emulsion
Σ^+	Cosmic rays	Decay at rest	Nuclear emulsion
Σ^-	Accelerator	Decay in flight into $\pi^- + n^0$	Diffusion chamber
Σ^0	Accelerator	Decay in flight into $\Lambda^0 + \gamma$	Bubble chamber
Ξ	Cosmic rays	Decay in flight into $\pi^- + \Lambda^0$	Wilson cloud chamber
Ξ^0	Accelerators	Decay in flight into $\pi^0 + \Lambda^0$	Bubble chamber

International Collaboration

By assembling many sheets of emulsion, it was possible to build up a large sensitive volume for recording tracks. Whereas, in the early days, only a single layer of emulsion had been available, so that only a small fraction of the charged particles originating in disintegrations within it were observed to reach the end of their range, in the new conditions the tracks could be traced from one emulsion to the next throughout a large stack. The field of application of the method was thereby greatly increased; particles of much greater energy could be followed to the end of their range, and their nature and kinetic energy could be determined. Whereas the early experiments on cosmic rays in 1947 had been made with emulsions with a total volume about 0.1 cubic centimeter, already by 1955 stacks made up of several hundred sheets 0.6 millimeter thick, and with a total volume of 7 liters, were widely employed.

It is these developments that provided the necessary background and experience for the extensive international collaborations in the study of nuclear collisions at extremely high energies which are now being carried out. These operations involve exposing balloon-borne stacks 80 liters in volume to the cosmic radiation at altitudes above 100,000 feet for periods of about 20 hours.

Science in the News

Disarmament: American Position Is Awkward: Neutralists Skeptical of United States Intentions

The United States won a procedural victory on the disarmament question at the United Nations last week. Khrushchev's proposal for a full dress debate in the General Assembly was defeated 52–13. But the vote indicated only the assembly's refusal to go along with the Soviet proposal to depart from normal procedure by bypassing the Political Committee, where the question would normally be considered. It did not imply a preference for the American view on disarmament or a rebuff of the Soviet view. The awkwardness of the American position remained unchanged as the formal debate in the Political Committee began this week.

As noted here last week, considerations of national self-interest which lead the United States to talk mostly of controls and which lead the Russians to talk of immediate disarmament are a basic source of American awkwardness. Neither side has given any indication that it seriously expects much progress to be made, and neither has much basis for a claim of moral leadership. The fact remains, though, that the American proposals have less popular appeal than the Russian proposals, particularly among the uncommitted nations.

But considerations of national self-interest are only the beginning of the source of American awkwardness. Some of the difficulties stem from the nature of American society and of America's position in the world, and they are things which are American strong points even if they lead to awkwardness on a specific issue like disarmament. Others, though, are clearly weaknesses which the Democrats, publicly, and many leading Republicans (including Nixon), privately, acknowledge to be things the next President will have to do something about.

That America is an open society and Russia is not is a source of awkwardness, as is the fact that the nations of the world, in general, expect more of the United States than they do of the Soviet Union. The openness of American society contributes, of course, to the basic tactical disadvantage of the United States described last week because it forces Americans to worry a great deal more about the dangers of inadequate control and inspection procedures than the Russians. But beyond this, it puts this country at a disadvantage on any question where the private views of its individual citizens differ from the official view of its government.

Skepticism on Both Sides

There is no question that the Russians are as skeptical of the likelihood of making real progress on disarmament as we are. Gomulka of Poland gave the General Assembly a shrewd and reasonable presentation of the Communist point of view on disarmament. In the course of his remarks he mentioned that experts on both sides recognize that it is possible that controls can increase rather than decrease the chance of war. But the same sort of analysis that leads to the unpleasant conclusion that certain kinds of controls can increase rather than decrease tension also leads to the even more unpleasant conclusion that certain types of disarmament can increase rather than decrease tensions. This particularly applies to disarmament without adequate controls.

A Russian at the United Nations, talking privately about disarmament, blandly remarked that he really didn't think anything was going to be accomplished until after there had been a general lessening of East-West tensions. This is the common view on both sides, but not the official view on either side. Both East and West have placed resolutions before the Political Committee reaffirming their support of immediate steps to get general and complete disarmament underway. But while convincing evidence of the skepticism with which American officials and students of disarmament regard such proposals is readily available to anyone who can read English, the private doubts of their Soviet counterparts do not find their way into any Soviet publications. And beyond the skepticism with which American officials regard progress towards disarmament, the foreigner also becomes aware that there are Americans who are simply opposed to disarmament or to negotiating with the Russians at all; to be told that such and such a senator or such and such a retired admiral does not really have any influence does not completely reassure these foreigners. Undoubtedly there are people with similar views in Russia, but, once again, such views do not find a public outlet in the Soviet scheme of things. This does not mean that anyone takes the Russian proposals without a grain of salt. But it does leave the Russians with some advantage since people know that the United States is skeptical about disarmament while they can only suspect that the Russians are.

Beyond this, the world in general expects more of the United States than of the Soviet Union. The United States is the leading nation in the world, and although the Russians have convinced quite a few people that this will not continue to be the case much longer, the United States is still regarded as pre-eminent and therefore as the nation which ought to be taking the initiative in such an important matter as disarmament. This places a burden on the United States, although hardly an unwanted burden. For not many responsible Americans look forward to a day when the world will no longer expect more of America than of the Soviet Union.

Under present circumstances the United States is in an awkward position when the Russians, as they do at every opportunity, say that, if the West will agree to some disarmament proposals, the Russians will then agree to whatever controls are necessary to assure everyone that these proposals are being carried out. No one blames the United States for doubting that the Russians would actually agree to adequate controls as they say they would. But almost

everyone seems to blame the United States for not taking up the Russian challenge, agreeing to some disarmament, and thus putting it up to the Russians to demonstrate their often-stated readiness to agree to controls. Since no one is suggesting that disarmament proposals, even if agreed upon, should go into effect until after agreement has been reached on controls, it is a common view, particularly among the neutralists, that the United States is holding things up, without any really sound reason for doing so. The actual situation is more complex than this simple view suggests, but this view, nevertheless, makes sense to a good many people at the U.N., including some Americans.

Pushing further, the Russians argue that they have as much reason as the Americans to want adequate controls. They scoff at the idea that America could not cheat on a disarmament agreement because it is an open society. How many people, ask the Russians, knew about the U-2 flights? This is not an unanswerable argument, for the fact remains that it would be much easier for the Russians to cheat than for the Americans to do so, and therefore controls that might be adequate to reassure the Russians are not likely to offer an equivalent amount of reassurance to the United States. But it is still an argument that does carry some weight.

Relative Military Power

The question remains, why doesn't the United States take the initiative by agreeing to some disarmament measures and putting it up to the Russians to come to terms on control? In part the answer is, as noted here last week, that American officials have good reason to suspect that the Russians are not yet ready to accept adequate controls, and that if the United States agrees to some steps on disarmament it will find itself in the position of either having to go through with the agreement on Russian terms, without adequate controls, or else of disappointing the world by backing out of the agreement.

Since a reduction in armaments is easy to understand while the adequacy or inadequacy of given controls is not, the United States has reason to fear that it will look bad if it finds itself forced to back out of a disarmament agreement, no matter how justified the American refusal to go ahead on Russian terms might be.

But aside from this tactical problem, there is the simple fact that many responsible Americans are uncertain whether the United States can afford to agree to start arms reductions right away, and the more complicated fact that the nature of the American system makes it difficult to reach an agreement within the government on what kinds of arms reduction might be agreed to. A Russian, again talking privately, remarked that the Soviet Union was not prepared for serious disarmament negotiations until the late 1950's because it was weaker than the United States. It is assumed that any disarmament arrangements will be aimed at keeping the relative military power of the disarmament nations stable as the over-all level of armament is reduced. Thus, until the Russians felt that their military strength was satisfactory in relation to American strength they were not ready for serious disarmament negotiations. Today the shoe seems to be on the other foot. The Rockefeller, Gaither, and Coolidge studies have all criticized what they saw as the inadequacy of the American defense effort, and this view appears to be held by almost everyone in Washington outside the White House.

Kennedy, explicitly, and Nixon, implicitly, have made it clear that they will recommend increases in the defense budget. The suppressed report of the Coolidge Commission on disarmament policy is believed to have specifically recommended that the United States needs several years to build up its defenses to the point where it will be in a position to enter serious negotiations with the Russians on arms reduction. The net effect of this widely assumed relative weakness is not only to restrict the United States freedom to make concessions to the Russians in order to demonstrate that the United States is ahead of the Russians in terms of what we are willing to do in order to make progress on disarmament; it also makes reaching agreements just so much more difficult.

A Russian, asked why the Soviet Union shows so little interest in Eisenhower's proposals to ban nuclear weapons from outer space, replies quickly that Russia would be foolish to do so, because Russia is ahead in outer space. Critics of American policies argue that the risks of the arms race are so enormous that the risks involved in moving toward disarmament are small by comparison. This feeling is becoming increasingly widely held; but it also seems to be the case that the Russians are not likely to participate in the real exchange of concessions necessary from both sides so long as they feel that American proposals on disarmament are based on weakness rather than strength: that is, on American fear that America is losing out to the Russians in a given area rather than on American confidence that it can match or beat the Russians but that it is in the mutual interest of both countries to arrange to refrain from the race.

The Russian's belief in their superior strength may be only an illusion. But as long as it exists it makes serious disarmament negotiations difficult. The unsatisfactory American defense posture, real or imagined, is far from the whole source of American awkwardness on disarmament, and perhaps it is not even the most important factor; but it exists and adds just so much more difficulty to the problem.

And finally, beyond all the real and apparent sources of American awkwardness on disarmament, comes the fact that peculiarities of the United States political system make it difficult for this country to reach agreement internally on what sort of disarmament proposals might be put forward at the United Nations. There is a great deal of logic to the claim that there ought to be a real unification of the armed forces, but the logic does not alter the political fact that real unification is not likely to move very fast. For any proposal for reform arouses opposition from everyone who fears that his service will lose something through the reform and who manages to deduce that his disinterested concern for the national welfare requires him to oppose the move. Every important faction in the Pentagon has sources of support in Congress and elsewhere throughout the country, which makes it very difficult to make progress on reorganizing the defense department despite almost everyone's profession that he favors some sort of reorganization. Similarly, any proposal for disarmament implies that some section of the armed forces is going to be weakened, and since everyone tends to be convinced that his particular area of concern is uniquely important to national defense, it is very hard to think of any disarmament proposal that would not arouse strong opposition from someone in the Pentagon and from his supporters outside—H.M.

News Notes

Senate Studies Salvaging of Data from $2.1 Billion in Cancelled Defense Research

The Senate Subcommittee on Reorganization and International Organizations reported last week that it is studying the efficiency with which research information is salvaged from cancelled research projects. During the last 3 years the Department of Defense has cancelled some $2.1 billion of research on weapon systems prior to completion of the projects. The review is part of an analysis of government scientific information programs, to be completed by 31 January 1961.

Largest of the cancelled projects were Navaho, $679.8 million; Rascal, $448 million; Sea Master, $387 million; and Regulus, $210 million. This information was included in a statement to the subcommittee provided by Herbert York, director, Office of Defense and Engineering, Department of Defense. York's statement included only projects whose total cumulative obligations before termination involved $10 million or more.

In describing the survey, Senator Hubert H. Humphrey, subcommittee chairman, pointed out that the Department of Defense does have a procedure for salvaging information from cancelled projects through filing of termination reports. He noted that the department is cooperating closely with the subcommittee in making available information on its index-control systems on research projects, particularly in the electronics field.

Every project involves hundreds of subprojects, tasks, and subtasks. The Senate group hopes to determine how well these are reported on, indexed, and consulted in order to avoid wasteful repetition of experiments.

Weisskopf To Head European Organization for Nuclear Research

Victor F. Weisskopf, president of the American Physical Society and professor of physics at Massachusetts Institute of Technology, is to head the 12-nation European Organization for Nuclear Research in Geneva, according to a report by Walter Sullivan in Monday's New York *Times*. The appointment is somewhat unusual because the United States is not a member of the international research center, known as CERN.

Weisskopf was born in Vienna and became a naturalized United States citizen in 1943. He worked at the Institute of Technology in Zurich, where Albert Einstein developed his theory of relativity, and was associated with Niels Bohr at the University of Copenhagen.

Weisskopf succeeds Cornelius J. Bakker of the Netherlands, who was killed last spring in an airplane accident in the United States. John B. Adams of England has been serving as acting head of CERN. He will return to his own country to direct research on the controlled fusion reaction. Weisskopf is expected to hold his post in Switzerland for 3 years and then return to M.I.T.

Biological Abstracts Holds Dedication

Biological Abstracts dedicated its new headquarters in Philadelphia 6–7 October with housewarming ceremonies for which Wallace O. Fenn, president of the board of trustees, served as host. Fenn, professor of physiology at the University of Rochester School of Medicine and Dentistry, welcomed attending biologists and scientific information specialists at proceedings that featured a symposium on scientific communication. In his opening remarks, Fenn spoke of the growth of the organization, which abstracts biological literature from all over the world. He said: "Our growth has been dramatic because we are a product of the creativity of Science. . . ."

Organized in 1926, Biological Abstracts was for many years housed in facilities provided, rent free, by the University of Pennsylvania. In 1958, the adjoining buildings that have just been dedicated were purchased. Internally, they have been virtually reconstructed.

Washington University Faculty Supports Pauling; 187 Sign Protest

Some 187 members of the faculty of Washington University signed a letter to the Senate Subcommittee on Internal Security that protests the committee's efforts to "interfere with Dr. Linus Pauling's fulfillment of his solemn obligations to his profession, to our nation and to humanity." In 1958 Pauling submitted a petition to the United Nations which called for an international agreement to stop nuclear weapons tests. Of the 11,021 scientists who signed the petition, more than 2000 were American, 104 of them members of the United States National Academy of Sciences.

Donald F. Murphy, treasurer of the board of trustees, Biological Abstracts; Wallace O. Fenn, president; and G. Miles Conrad, director.

The subcommittee subpoenaed Pauling and demanded that he provide the committee with his record of the names of those who helped him circulate the petition. Pauling has refused, risking a contempt citation.

The Washington letter signers say: "We are proud that this petition was drafted, and the movement for its circulation was started, on the occasion of Dr. Pauling's visit at Washington University as Eliot Honors Day speaker in May, 1957. . . . That a committee on internal security should concern itself with this matter clearly indicates that its members fail to recognize that Dr. Pauling and his associates have performed a service of the highest patriotism. . . .

"That Dr. Pauling, at personal risk, has chosen to resist the subcommittee's demand is added evidence of his profound devotion to the obligations of a scholar and a citizen.

"We call upon our colleagues, our fellow citizens, and our representatives in Congress to join in putting an end to the subcommittee's present course of action."

Contempt Citation Less Likely

Although it is still possible that a criminal charge of contempt of Congress may be brought, it is far less likely now than it was before the committee session of 11 October, for which Pauling received a second subpoena. Such action cannot be taken on the basis of the hearing record so far, for Pauling has not yet been, and may never be, ordered finally to produce the documents at issue.

When Senator Thomas J. Dodd (D-Conn.), acting subcommittee chairman, asked for the list of names, Pauling's attorney entered a legal objection on which Dodd never ruled. The Supreme Court has said that a Congressional witness cannot be convicted of contempt unless the hearing committee has definitely overruled all objections and clearly directed the witness to comply with its request.

News Briefs

Antimicrobial agents. A Conference on Antimicrobial Agents will meet at the Mayflower Hotel in Washington, D.C., 26–28 October, under the sponsorship of the Society for Industrial Microbiology, a nonprofit organization of scientists and engineers in university, governmental, and industrial research. Selman A. Waksman, 1952 Nobel laureate, is honorary chairman of the conference and will present the keynote address. Officers of the meeting anticipate the participation of some 500 scientists—from Japan, Czechoslovakia, West Germany, Austria, England, Canada, and Haiti, as well as the United States.

* * *

German professors visit. A new teaching hospital is being planned for the Free University of West Berlin to provide facilities for the medical faculty. Fourteen professors from West Berlin visited the University of Chicago on 14 October to study its medical school as a model which they may wish to emulate. The buildings for the German hospital are to be financed jointly by the West Berlin Government and the United States Government, with design and construction determined by the Benjamin Franklin Foundation, a joint United States-German nongovernment group. The U.S. representatives are chiefly architects. Medical advice has been given by Jack Masur of the Clinic Center of the National Institutes of Health, Basil McLean, hospital administrator, and Russell Nelson, director of the Johns Hopkins Hospital.

* * *

Microbiology. Sixty microbiologists, half of them from abroad, will report on their research at a Symposium on Marine Microbiology to be held in the Morrison Hotel, Chicago, 20–24 April 1961. The symposium is being sponsored by the Office of Naval Research and the Society of American Bacteriologists, in cooperation with the American Institute of Biological Sciences. Program chairman is Carl H. Oppenheimer of the University of Texas Institute of Marine Science, Port Aransas, Tex.

* * *

Orbiting observatory planned. The National Aeronautics and Space Administration will negotiate with Grumman Aircraft Engineering Corporation, Bethpage, N.Y., on a contract to develop a 1.5-ton orbiting astronomical observatory. Astronomers will use telescopes in the orbiting observatory space platform to study cosmic phenomena—x-rays and ultraviolet and infrared rays—obscured from the ground by the earth's atmosphere.

The Grumman proposal, one of 11 submitted in July, requires negotiation of a contract for approximately $23 million, not including the cost of the experiments. Grumman proposes an eight-sided satellite, 9.5 feet high and 6.5 feet in diameter. It will weigh about 3200 pounds, including 1000 pounds of experimental equipment. Two flight model orbiting observatories will be built under the contract, the first to be delivered in 2.5 years.

* * *

IAEA mission to Latin America. A preliminary assistance mission of the International Atomic Energy Agency left Vienna on 16 October for Mexico, El Salvador, Guatemala, Peru, and Paraguay. It is headed by Arturo Cairo of IAEA's Training and Exchange Division, formerly head of the chemistry department of the Atomic Energy Commission of Argentina and professor of inorganic chemistry on the Faculty of Sciences, University of Buenos Aires. The mission, which is expected to return to Vienna on 24 November, will spend about 1 week in each of the five countries. Other members of the IAEA team are Carlos Buchler, Robert Dudley, Subhas Dhar, Peter Nye, and John Webb.

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UNESCO conference on Africa. The U.S. National Commission for UNESCO, which has just concluded its 2-day annual meeting, has announced that next year's conference will focus on Africa south of the Sahara. Vernon McKay, vice president of the African Studies Association and professor of African studies at Johns Hopkins University, was appointed chairman of a National Commission committee to plan and organize the conference, which will be held in Boston, 23–26 October 1961. Boston University will be host, and a special organizing committee will also be set up in Boston.

* * *

Stanford Radio Astronomy Institute. A new Radio Astronomy Institute has been formed at Stanford University to implement an expanded research program in which distinguished visiting scientists will take part. Experts from Japan and Australia already have made visits under the aegis of the institute, which will support a continuing group of such visiting specialists to augment the Stanford research staff.

The Air Force Office of Scientific Research sponsors the new organization, which is directed by Ronald N. Bracewell, the professor who designed and built Stanford's 32-dish radio telescope. An advisory committee of specialists from the Stanford Electronics Laboratories and the Radioscience Laboratory assists him in administering the institute.

Scientists in the News

Gold Heart Awards, highest honor of the American Heart Association, were presented at the association's annual dinner in St. Louis on 23 October to **Herrman L. Blumgart**, professor of medicine, Harvard Medical School, and physician-in-chief, Beth Israel Hospital, Boston, and **Robert L. King**, clinical associate professor of medicine, University of Washington School of Medicine, Seattle. Blumgart was cited for his services as editor-in-chief of *Circulation*, one of the four professional journals of the association, and King, a former AHA president, was honored for having "helped to sharpen our program objectives and to strengthen our scientific leadership on the continuing fight against cardiovascular diseases."

Rebecca C. Lancefield of the Rockefeller Institute received the third T. Duckett Jones Memorial Award of the Helen Hay Whitney Foundation on 8 October at a dinner held in her honor in Princeton, N.J. The award, in the amount of $6500, was conferred for "her long and continuing studies which are so largely responsible for the present knowledge of the biology of hemolytic streptococci."

The presentation took place during the Whitney Foundation's third annual meeting of research fellows and established investigators and second Connective Tissue Conference. Dr. Lancefield is the second woman to be named a full professor by the Rockefeller Institute and the first woman to receive the Jones Award.

The National Aeronautics and Space Administration has announced appointment of 28 outstanding scientists to three Office of Life Science advisory committees. The committees (which will meet three or four times a year) and their chairmen are as follows: space biology (molecular biology, cellular environmental physiology, and extraterrestrial life), **Melvin Calvin**, professor of chemistry, University of California; space medical and behavioral sciences (neurophysiology and psychology, metabolism and nutrition, and cardiovascular and respiratory physiology), **Robert S. Morison**, director, medical and natural sciences, the Rockefeller Foundation; and flight medicine and biology (experiments in the space environment and biotechnology), **W. Randolph Lovelace, II**, the Lovelace Foundation.

Alan Gray, previously chief of the virology department, Microbiological Associates, Bethesda Md., has been appointed manager of biological development for Merck Sharp and Dohme Division of Merck and Co., West Point, Pa.

Conrad L. Longmire, physicist, has been appointed a member of the staff of the Avco-Everett Research Laboratory, Everett, Mass. He will be engaged in research pertaining to ballistic missile defense. For the past 11 years he has been on the staff of the Los Alamos Scientific Laboratory, Los Alamos, N.M., where he served as alternate leader of the theoretical division.

William C. Ashby, formerly of the botany department at the University of Chicago, has been appointed associate professor of botany at Southern Illinois University.

H. William Harris has been named professor and chairman of the department of medicine at the Woman's Medical College of Pennsylvania. Since 1955 he has been associate professor of medicine and head of the pulmonary disease division at the University of Utah College of Medicine, Salt Lake City, and chief of the pulmonary disease service of the Veteran's Administration Hospital in that city.

The Public Health Service has announced two staff changes in the office of the director, National Institutes of Health.

Charles V. Kidd, at present chief of the office of program planning, will become associate director for institutional relations.

Joseph S. Murtaugh, now serving as assistant chief of the office of program planning, will succeed Kidd as chief of the office. In his new position Kidd will be a member of the NIH director's policy staff and the leading adviser on the development of NIH relations with educational and research institutions. His principal function will be the evaluation of the total effect of all NIH research grants and fellowships on such institutions.

John P. Wise, biologist at the Fisheries Laboratory, Woods Hole, for the past 7 years, is transferring to the Food and Agriculture Organization of the United Nations to serve as an adviser in fisheries biology in Argentina, Brazil, and Uruguay.

The first Distinguished Service Awards of the Minnesota Medical Foundation were recently presented to **Maurice B. Visscher**, head of the department of physiology at the University of Minnesota, and **Owen H. Wangensteen**, head of the university's department of surgery. The two men were honored in a surprise ceremony with certificates and accompanying awards which will pay them each $5000 annually until retirement.

John B. Kaiser has accepted appointment as the executive director of the American Documentation Institute, a professional society founded in 1937 for the discussion, publication, and critical analysis of work dealing with the theory, practice, research, and development of all elements involved in the communication of recorded specialized information. Members include physical and social scientists, technologists, administrators, librarians, information specialists, and documentalists.

In addition, **Luther H. Evans**, formerly Librarian of Congress and director of UNESCO, has been appointed editor of *American Documentation*. The ADI has temporary offices at 1025 Connecticut Ave., NW, Washington, D.C.

R. J. North, senior scientific officer at Britain's National Physical Laboratory, Teddington, will be in the United States for approximately 10 days, commencing about 16 October. His tour will include participation in the 5th International Congress on High Speed Photography in Washington, D.C.

G. Popjak, director of the Medical Research Council's Experimental Radiopathology Research Unit, London, will spend the fall working at the National Heart Institute.

Winners of 17 awards which are administered by the American Chemical Society were announced at the 138th ACS national meeting that was held recently in New York. Most of the awards will be presented next spring at the 139th national meeting of the ACS in St. Louis. At that time the Priestley Medal, the Society's highest honor, will also be presented. The 17 winners are as follows:

R. B. Woodward, Donner professor of science at Harvard University—Roger Adams Award in Organic Chemistry.

Melvin S. Newman, professor of chemistry at Ohio State University—ACS Award for Creative Work in Syn-

thetic Organic Chemistry, sponsored by the Synthetic Organic Chemical Manufacturers Association.

John J. Katz, senior research chemist, Argonne National Laboratory—ACS Award for Nuclear Applications in Chemistry, sponsored by the Nuclear-Chicago Corporation.

Frederick L. Crane, associate professor of biological sciences, Purdue University—ACS Award in Biological Chemistry, sponsored by Eli Lilly and Company.

Marcel J. E. Golay, consultant, instrument division, Perkin-Elmer Corp. —ACS Award in Chemical Instrumentation, sponsored by E. H. Sargent & Co.

Harold H. Strain, senior chemist, Argonne National Laboratory—ACS Award in Chromatography and Electrophoresis, sponsored by Labline, Inc.

Olaf A. Hougen, professor of chemical engineering, University of Wisconsin—ACS Award in Industrial and Engineering Chemistry, sponsored by the Esso Research and Engineering Company.

George S. Hammond, professor of organic chemistry, Gates and Crellin Laboratory, California Institute of Technology—ACS Award in Petroleum Chemistry, sponsored by Precision Scientific Company.

Eugene E. van Tamelen, professor of Chemistry, University of Wisconsin —ACS Award in Pure Chemistry, sponsored by Alpha Chi Sigma Fraternity.

Vladimir N. Krukovsky, professor of dairy and food science, New York State College of Agriculture, Cornell University—ACS Award in the Chemistry of Milk, sponsored by the Borden Company Foundation, Inc.

H. A. Laitinen, professor of analytical chemistry, University of Illinois—Fisher Award in Analytical Chemistry.

C. S. Seidel, Scientific Collaborator of Firmenich & Cie., Federal Polytechnical Institute, Zurich—Fritzsche Award.

Sarah Ratner, member of the division of nutrition and physiology, Public Health Research Institute of the City of New York—Garvan Medal.

David Dietz, science editor, Scripps-Howard Newspapers—James T. Grady Award.

Stephen Brunauer, manager of the basic research section at Portland Cement Association—Kendall Company Award in Colloid Chemistry.

Frank Huennekens, associate professor of biochemistry, University of Washington School of Medicine—Paul-Lewis Laboratories Award in Enzyme Chemistry.

John C. Bailar, Jr., professor of chemistry, University of Illinois—Scientific Apparatus Makers Award in Chemical Education.

Brigadier General **William M. Thames, Jr.**, commanding general of the U.S. Army Combat Surveillance Agency, Arlington, Va., has been named commanding general of the newly established U.S. Army Advent Management Agency, Fort Monmouth, N.J. Development of a communication system utilizing a 24-hour communication satellite is the objective of Project Advent, which was recently transferred from the Advanced Research Projects Agency to the Army. The U.S. Army Advent Management Agency was established by the Army Signal Corps to provide over-all management and technical direction of the Army's responsibilities in the program. The agency will be assisted by a specially selected group of officers and scientists.

Serving as deputy commander of the new agency will be Colonel **John W. Schroder**, now chief officer for ammunition operation of the U.S. Army Ordnance Special Weapons-Ammunition Command, Picatinny Arsenal, Dover, N.J.

Recent Deaths

Brooks A. Brice, Philadelphia, Pa.; 56; physicist with the U.S. Department of Agriculture for 30 years and head of the department's animal fat properties laboratory in the Eastern Utilization Research and Development Division, Wyndmoor, Pa.; noted for his developments and inventions in the field of color and spectrophotometry; 19 Sept.

Herman T. Briscoe, Indianapolis, Ind.; 66; chemist and retired vice president and dean of faculties of Indiana University; author of four books, including a widely used general chemistry textbook; during World War II, served in Washington as chief of the division of professional and technical training in the War Manpower Commission; 8 Oct.

Wesley R. Coe, San Diego, Calif.; 93; professor emeritus of biology at Yale University; after retirement in 1937, served as a research associate at Scripps Institution of Oceanography, La Jolla, Calif., for 18 years; 21 Sept.

Donald M. Davidson, Minneapolis, Minn.; 58; president of the E. J. Longyear Company, Minneapolis, and an internationally known geologist; served as a consultant to a number of government agencies, boards, and commissions and was a former president of the Society of Economic Geologists; between 1928 and 1939, rose to chief engineer for Selections Trust, Ltd., London; 15 Sept.

Melanie Klein, London, England; 78; one of Britain's foremost child psychologists; developed the technique of "play therapy," basing her studies of emotional disorders in children on systematic observation of their play, a method that was adopted with various modifications by child guidance clinics throughout Western Europe and the United States; 22 Sept.

Alfred Kroeber, Berkeley, Calif.; 84; internationally known anthropologist who taught at the University of California for almost 40 years and for whom the university's new anthropology building, Kroeber Hall, was named in 1958; author of the authoritative textbook *Anthropology* and of a number of important works on American Indian tribes; after retirement in 1946, accepted visiting professorships at Harvard, Columbia, and Brandeis universities and, in 1955, a fellowship at the Center for Advanced Study in Behavioral Sciences at Stanford University; in 1945 received the Huxley Medal, highest honor given by the Royal Anthropological Institute of Great Britain, and the next year, the Viking Medal, from the American Anthropological Association; a former president of the American Folklore Society and the American Anthropological Association; 4 Oct.

William M. Mann, Washington, D.C.; 74; retired in 1956 after 31 years as director of the Washington zoo, which is operated by the Smithsonian Institution; was assistant director of the Mulford Biological Exploration in the Amazon Basin in 1921–22, director of the Smithsonian Chrysler Expedition to Africa in 1926, and director of the National Zoological Park expeditions to British Guiana in 1931, to Argentina in 1938, and to Liberia in 1940; in 1937 directed the National Geographic Society expedition to India; 10 Oct.

Burt M. McConnell, New York, N.Y.; 72; arctic explorer, writer, and editor; was an assistant to Vilhjalmur Stefansson and was meteorologist on the Canadian Arctic Expedition in 1913–14; was on the editorial staff of the *Literary Digest* from 1919 to 1929, and later edited the *Explorers Journal*; 24 Sept.

Book Reviews

Advances in Computers. vol. 1. Franz L. Alt, Ed. Academic Press, New York, 1960. x + 316 pp. Illus. $10.

Mathematical Methods for Digital Computers. Anthony Ralston and Herbert S. Wilf, Eds. Wiley, New York, 1960. xi + 293 pp. Illus. $9.

Progress in Automation. vol. 1. Andrew D. Booth, Ed. Academic Press, New York; Butterworths, London, 1960. viii + 231 pp. Illus. $8.50.

Automatic Data-Processing Systems. Principles and procedures. Robert H. Gregory and Richard L. Van Horn. Wadsworth, San Francisco, Calif., 1960. xii + 705 pp. Illus.

Management Organization and the Computer. George P. Shultz and Thomas L. Whisler, Eds. Free Press, Glencoe, Ill., 1960. xvii + 257 pp. $7.50.

The literature on computers has many facets which reflect the manifold applications of these instruments in our everyday life. A glance at volume 1 of *Advances in Computers*, the first of a new series, is sufficient to demonstrate that the role of the computer is not confined to the scientific and engineering calculations for which the early computers were developed. Side by side with the articles "Numerical weather prediction" and "Binary arithmetic" appear the papers "General-purpose programming for business applications," "The present status of automatic translation of languages," "Programming computers to play games," and "Machine recognition of spoken words." Each of these survey articles is written by an authority in the field and is accompanied by a comprehensive bibliography. Almost all indicate the progress made in the field to date, as well as the work still to be done before the problems involved can be considered solved, if, indeed, they ever can be. Thus Bar-Hillel makes a strong case for the impossibility of ever achieving fully automatic high quality translation by computers. On the other hand, there is reasonable expectation that weather can eventually be predicted with great accuracy by machines.

The use of a computer as a calculating instrument is most fully realized when it solves scientific and engineering problems. For this purpose, the branch of mathematics called numerical analysis provides the tools with which these problems, once they have been well formulated in mathematical terms, can be tackled to yield numerical results. Because automatic digital computers operate much faster than hand computers and have different logical characteristics, numerical analysis has undergone a tremendous upheaval with their appearance. The greater speed and capacity of these machines have made possible the use of techniques which were not feasible previously and have stimulated the search for new algorithms as more difficult problems are posed for solution. *Mathematical Methods for Digital Computers* is the first book which deals solely with computer-oriented numerical analysis.

The book consists of an introduction, which explains the general layout of each chapter, and 26 chapters, which are divided into six sections, on the generation of elementary functions, matrices and linear equations, ordinary differential equations, statistics, and miscellaneous methods. The last-mentioned category includes solutions of polynomial equations, quadrature, Fourier analysis, linear programming, and network analysis. The layout of each chapter except the first, which is of a special nature, is uniform and follows this outline: function of method, mathematical discussion, summary of the calculation procedure, flow chart with description, subroutines needed, sample problem, memory requirements, estimation of running time, and references. The individual chapters are written by experts in the different fields, and hence the treatment is uneven. Some authors treat the problem in its full generality, from beginning to end, while others deal adequately with the theory but treat only a simplified version in the flow chart. In addition, several fairly widespread methods are omitted, while others of limited application are included. However, this is a good first effort to fill a gap in the rapidly growing literature on computers.

Among the many users of computers, the large industrial concerns are best able to exploit their diverse capabilities to the utmost. Thus, in addition to performing the scientific calculations associated with research and development and with mathematical programming, the computer is used to handle the paper work of the firm and to control the manufacturing process. This latter use is, at present, a fringe use of computers, but its importance is bound to increase with time. *Progress in Automation* is devoted to British experience in this field. This collection of articles consists of an introduction by the editor and two parts, "Methods" and "Applications." The papers in part 1 deal with some of the fundamental tools and techniques useful in automation, while those in part 2 discuss systems which are already in operation and which have a computer as one of their principal components. The articles are fairly technical and should be of great interest to engineers concerned with the field.

The information-handling aspect of computers is becoming more and more widespread, and we no longer speak of computers but of data-processing systems. A very thorough treatment of this field is given in *Automatic Data-Processing Systems*. Its 22 chapters are divided into seven parts: "Orientation," "Automatic equipment," "Programming and processing procedures," "Principles of processing systems," "Systems design," "Equipment acquisition and utilization," and "System re-examination and prospective developments." In addition there are three appendixes: "History of computation and data-processing devices," "Questions and problems," and "Glossary of automatic data-processing terminology." Each paper is followed by a detailed summary, which indicates the coverage of the chapter, and by a list of references and supplemental readings. (These entries are accompanied by a brief summary of their contents, which greatly increases their usefulness.) Finally, there are 11 tables giving up-to-date information on most of the data-processing systems now on the market. This work contains a storehouse of information suitable for the needs of the various groups concerned with data processing.

and the authors are to be congratulated for the excellent presentation.

Of more limited scope is the book *Management Organization and the Computer*, which is the proceedings of a seminar sponsored by the graduate school of business of the University of Chicago and by the McKinsey Foundation. This book is concerned with the changes a company has to undergo when a computer is introduced. It contains articles relating to what the editors call information technology as well as articles relating to the concepts and problems of organization. An additional series of articles involves the experience of five companies that have installed computers. Many of these papers are followed with discussions and comments made by the participants; these remarks help clarify the subject matter. The book is intended for the higher levels of management where major decisions are made; the decision to install a data-processing system in a company, with all the upheaval involved in such an act, is indeed a major decision. However, in view of the rapidly increasing flow of information throughout the business enterprise, the question is not whether to install a computer, but rather how to do it most efficiently. This book should help to find the answer.

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Henry Cavendish. His life and scientific work. A. J. Berry. Hutchinson, London, 1960. 208 pp. Illus. 35s.

When Cavendish died in 1810, Humphry Davy said of him: "His name will be an object of more veneration in future ages than at the present moment . . . it will remain illustrious in the annals of science. . ." In a biography of Cavendish published in 1851, George Wilson probed deeply into the "water controversy" between Priestley, Watt, Cavendish, and Lavoisier; Wilson's study of what these men meant by *inflammable air* and *phlogiston* is still indispensable to the specialist. Since then, Cavendish's many unpublished papers have become available in print. Now Berry gives us the first comprehensive survey of this work which extended to many different fields of science. This man of "morbid shyness and timidity" had "the remarkable gift of knowing almost intuitively what kinds of problems were worth investigation" (page 21). Berry considers him to be the founder of water analysis and points out that Cavendish had clear concepts of chemical proportions and equivalent weights. In a paper published in 1781, Cavendish spoke of the particles of his electric fluid, but he adhered to Newton's opinion of heat as the internal motion of the particles of bodies against Black's hypothesis of a matter of heat. In his electrical researches he was, as Maxwell said, "his own galvanometer." This master of the accurate experiment noticed that "1/120 of the bulk of the phlogisticated air" remained unreactive. More than a century later this observation led to the discovery of the inert gases. Berry's account here conflicts with that of Ramsay himself.

The historians of science will be grateful to Berry for his well-balanced and thorough study. Those interested in "the" scientific method will find here much to capture their attention, particularly in Cavendish's approach to the problem of the "Electric Ray or Torpedo." Berry has painted a fascinating picture of a living embodiment of that abstraction, the pure scientist.

EDUARD FARBER
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Progress in Solid Mechanics. vol. 1. I. N. Sneddon and R. Hill, Eds. North-Holland, Amsterdam; Interscience, New York, 1960. xii + 448 pp. $15.50.

The aims and scope of this book are best described by quoting from its preface: "At the present time the mechanics of solids is perhaps the most rapidly expanding branch of applied mathematics. . . . It is becoming more and more desirable for engineers and physicists as well as applied mathematicians to study solid mechanics as a whole, and yet increasingly difficult for them to do so since important papers may appear in journals of widely differing character. This impasse may be met only by review articles of the highest standard which from time to time summarize and unify the most recent work in a particular field or group of fields. The present volume is the first in a series directed toward that end. The papers it contains are mainly concerned with reviewing recent theoretical studies in solid mechanics, but it is hoped that future volumes will contain surveys of recent experimental investigations. . . . The main emphasis [of this series] will be on basic principles and mathematical techniques of continuum mechanics, in all its aspects, together with experimental work of a fundamental kind."

The British editors are well qualified for this task, and it may be said that this first volume is highly successful in meeting the purpose set forth in the preface. Five of the contributors are British, and there is one each from Germany, Holland, and Japan. Five of the chapters cover subjects of rather broad general interest, while the other three discussions present results of more limited scope, yet of considerable interest.

The chapter on viscoelastic waves, by S. C. Hunter, is an interesting and logically developed account of the recent work on wave propagation in viscoelastic (or anelastic) materials. Both the Fourier and Laplace transform approaches are covered, with both their equivalence and the cases in which one or the other approach has practical advantages clearly pointed out. The various formulations of the constitutive equations applicable to linear materials showing viscoelastic or anelastic behavior are derived in a fashion suitable for the purposes of this chapter, although neither this section nor the discussion of the experimental results for polymers is, or was intended to be, complete.

The material on matrices of transmission in beam problems, by K. Marguerre, presents a formulation of the dynamics of framed structures with members of variable section not necessarily straight. Torsion can also be included. This paper should be of value to engineers and computers interested in numerical analysis.

H. G. Hopkins discusses the dynamic expansion of spherical cavities in metals produced by explosive loading. Although it is necessary to introduce drastic simplifications—such as neglect of the outgoing shock wave in the metal and the oscillatory character of the gas pressure in the early stages—in order to obtain a manageable problem, nevertheless it is possible to reach conclusions of both practical and theoretical interest.

W. T. Koiter presents a concise but quite complete survey of the general theorems of the mathematical theory of plasticity for isotropic bodies. Existence and uniqueness theorems are discussed, together with minimum principles and the bounds associated with limit analysis, including plastic collapse and shake-

down. Qualifications of the theorems are carefully stated. The development of this aspect of the theory of plasticity has reached relative maturity, and this review not only summarizes the material effectively but also gives the historical perspective of the development.

The presence of even the simplest boundaries in an elastic body with some finite dimensions introduces great complications in the behavior of elastic waves; in particular, there is usually dispersion. Because of the widespread use of high-frequency mechanical systems, such as crystal oscillators, marked interest has been shown in this subject in recent years. W. A. Green treats one aspect of this matter in a rather individualistic article on the dispersion of elastic waves in bars. The simplest case is the infinite bar of circular cross section, for which a formal solution was given by Pochhammer as early as 1876, but the complicated results have received quantitative study only in recent years. The dispersion curves for axial, torsional, and flexural waves consist, in each case, of an infinite number of branches. Exact solutions for cross sections other than circular have not yet been found. Consequently there has been much interest in approximate solutions, which are discussed at some length in the article. Where possible, comparisons are made with the lowest branch of the Pochhammer solution, but no attention is drawn to the fact that most of the theories furnish no approximations to the higher branches. The article concludes with an interesting discussion of the complications introduced when the Pochhammer theory is enlarged to include more than one nodal plane through the axis of the bar.

The account of the dynamical theory of thermoelasticity, presented by P. Chadwick, is as lucid and readable as any I have seen. A derivation of the field equations and the linearized constitutive relations in an isotropic body is followed by an extended account of plane harmonic thermoelastic waves in the manner of Biot. Lockett's analysis of thermoelastic Rayleigh waves, a treatment of the thermoelastic Pochhammer-Chree problem for an infinite circular cylinder, and a treatment of both axially and radially symmetric problems are presented. Following Biot, the author derives the constitutive relations in terms of the variables associated with the free energy—that is, the strain (or displacement) and the temperature. It is perhaps regrettable that the utility of the remaining thermodynamic functions is not exploited. For instance, consideration of the enthalpy leads directly to equations in the stress and (through the entropy) the heat flux, a very convenient choice in a problem such as that of a metallic rod driven by pulsed radiation incident on one end.

The concise review of continuous distributions of dislocations by B. A. Bilby, one who was most active in founding the theory, deals almost exclusively with the pertinent kinematics—that is, with formulation and physical interpretation of the relevant geometry. Since the discussion covers a wide variety of investigations, sometimes very briefly, it is impracticable to describe the contents in detail. Fundamental in the theory is a non-Riemannian geometry, involving an asymmetric affine connection. The antisymmetric part of this connection describes the distribution of dislocations. Curves everywhere tangent to crystallographic vectors are paths in this geometry, paths being analogs of the straight lines in Euclidean geometry. With this geometry and conventional kinematics, one can describe macroscopic "shape" deformation, lattice distortion, and deformation associated with introduction or movement of dislocations. These ideas are developed in some detail and correlated with dislocation theory. This approach promises to play an important role in the development of the mechanics of crystalline solids, and the present review provides a good starting point for those interested in learning what it entails.

The number of significant solutions to three-dimensional problems in elasticity is small except where the number of space variables can be reduced by conditions of axial or radial symmetry. It is therefore welcome to see an extension to asymmetric problems of the powerful method of integral transforms associated with Sneddon. R. Muki discusses elastic and thermoelastic (steady state) problems associated with the semi-infinite solid and the thick plate. Specific cases include the inclined rigid cylindrical punch and arbitrary tangential loading on the semi-infinite solid. Both loaded areas are circular, and Hankel transforms are used. Two thermal stress problems are solved for the thick plate with circular heated areas.

Particularly noteworthy are the uniformly excellent bibliographies attached to each article.

I hope that succeeding volumes in this series will maintain the high standard set by the first.

I am indebted to J. L. Ericksen, Johns Hopkins University, for reviewing the article on continuous distribution of dislocations and to my colleagues, R. S. Marvin and Martin Greenspan, who were kind enough to review the articles on viscoelasticity and thermoelasticity, respectively.

J. M. FRANKLAND
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The American Civil Engineer. Origins and conflict. Daniel Hovey Calhoun. Technology Press and Harvard University Press, Cambridge, Mass., 1960. xiv + 295 pp. Illus. $5.50.

This history covers the tribulations of the civil engineer in the United States from the colonial era until the 1840's, when "civil engineers had become a definite occupational group." The author is most concerned with the period from 1816 (the beginning of the New York state canal system) through the depression of 1837–46; apparently the depression gave the engineer the leisure necessary to reflect on his calling and to recognize the need for a professional society.

The problem of defining his work was approached scientifically by the engineer himself as early as 1830 when Amos Eaton subdivided the work into *ochetology*, *odology*, *mylology*, and *stereology*! But, as Calhoun shows, the engineer found it difficult in practice to differentiate himself from capital, on the one hand, and labor, on the other. In my opinion, Calhoun's analysis of the "trend" of things is unduly complex. In essence, it seems that the engineer's problem was to become a sufficiently numerous species to demand definition, and this was accomplished, thanks to the proliferating transportation projects sponsored by the government in the early 19th century.

All this is told at somewhat greater length than necessary and with an emphasis on socioeconomic analysis which effectively submerges the undoubted romance of civil engineering in those days. But, in an area heretofore almost entirely given over to legend, it is refreshing to encounter a report so solidly based on fact and footnote.

ROBERT P. MULTHAUF
Smithsonian Institution

Meetings

Forthcoming Events

November

3–4. Muscle as a Tissue, conf., Philadelphia, Pa. (Division of Research, Lankenau Hospital, Philadelphia 31)

4–5. West-Central States Biochemical Conf., Lincoln, Neb. (J. H. Pazur, Dept. of Biochemistry and Nutrition, Univ. of Nebraska, Lincoln)

4–6. Assoc. of Clinical Scientists, Washington, D.C. (R. P. MacFate, 54 W. Hubbard St., Chicago 10, Ill.)

5. Society for Industrial and Applied Mathematics, Philadelphia, Pa. (G. Kaskey, Remington Rand Univac, 1900 W. Allegheny Ave., Philadelphia)

7–10. Society of Exploration Geophysicists, 30th annual intern., Galveston, Tex. (C. C. Campbell, Box 1536, Tulsa, Okla.)

8–10. Forensic Sciences, 2nd symp., Washington, D.C. (Director, Armed Forces Inst. of Pathology, Washington 25)

9–10. Use of Secondary Surfaces for Heat Transfer with Clean Gases, symp., London, England. (Secretary, Institution of Mechanical Engineers, 1 Birdcage Walk, London, S.W.1)

9–11. Clinical Chemistry Methods, symp., Cleveland, Ohio. (A. Hainline, Cleveland Clinic, 2020 E. 93 St., Cleveland 6)

10–12. Geological Soc. of America, 73rd conv., Denver, Colo. (H. R. Aldrich, GSA, 419 W. 117 St., New York 27)

10–12. National Assoc. of Geology Teachers, Denver, Colo. (F. Foote, Dept. of Geology, Williams College, Williamstown, Mass.)

10–13. Pacific Coast Fertility Soc., Las Vegas, Nev. (A. C. Wineberg, 3120 Webster St., Oakland, Calif.)

11–12. Paleontological Soc., Denver, Colo. (H. B. Whittington, Harvard Univ., Cambridge 38, Mass.)

13–16. Society of American Foresters, 60th annual, Washington, D.C. (H. Clapper, SAF, 825 Mills Bldg., Washington 6)

14–17. Magnetism and Magnetic Materials, 6th annual conf., New York, N.Y. (L. R. Bickford, Jr., I.B.M. Research Center, Yorktown Heights, N.Y.)

14–18. American Soc. of Agronomy, Chicago, Ill. (L. G. Monthey, 2702 Monroe St., Madison 5, Wis.)

14–18. Nuclear Ship Propulsion, symp., Taormina, Sicily. (International Atomic Energy Agency, 11 Kärntner Ring, Vienna 1, Austria)

15–16. Engineering Application of Probability and Random Function Theory, symp., Lafayette, Ind. (J. L. Bogdanoff, School of Aeronautical and Engineering Sciences, Purdue Univ., Lafayette)

16–19. Society of Naval Architects and Marine Engineers, annual, New York, N.Y. (W. N. Landers, SNAME, 74 Trinity Pl., New York 6)

17–19. Extrapyramidal System and Neuroleptics, intern. symp., Montreal, Canada. (J.-M. Bordeleau, Dept. of Psychiatry, Univ. of Montreal, Montreal)

17–19. Surgery of Endocrine Organs, symp., New York, N.Y. (Office of the Associate Dean, New York Univ. Post-Graduate Medical School, 550 First Ave., New York 16)

17–20. American Anthropological Assoc., Minneapolis, Minn. (B. J. Meggers, 1530 P St., NW, Washington 5)

17–20. Southern Thoracic Surgical Assoc., Nassau, Bahamas. (H. H. Seiler, 517 Bayshore Blvd., Tampa 6, Fla.)

18–19. American Medical Writers' Assoc., Chicago, Ill. (H. Swanberg, 510 Maine St., Quincy, Ill.)

21–23. Fluid Dynamics, annual, Baltimore, Md. (R. J. Emrich, Div. of Fluid Dynamics, APS, Dept. of Physics, Lehigh Univ., Bethlehem, Pa.)

24–25. American Physical Soc., Chicago, Ill. (K. K. Darrow, APS, 538 W. 120 St., New York 27)

24–26. Central Assoc. of Science and Mathematics Teachers, 60th annual conv., Detroit, Mich. (L. A. Conrey, School of Education, Univ. of Michigan, Ann Arbor)

25–26. American Soc. of Animal Production, Chicago, Ill. (C. E. Terrill, Animal Husbandry Research Div., Agricultural Research Center, Beltsville, Md.)

25–26. National Council for Geographic Education, Cincinnati, Ohio. (L. Kenndmer, Univ. of Texas, Austin)

25–16. Bahamas Medical Conf., Nassau. (B. L. Frank, P.O. Box 4037, Fort Lauderdale, Fla.)

27–1. Latin American Cong. of Neurology, Santiago, Chile. (R. Nunez, Almirante Montt 485, Dep. 11, Santiago)

27–2. American Soc. of Mechanical Engineers, annual, New York, N.Y. (A. B. Conlin, Jr., ASME, 29 W. 39 St., New York 18)

27–5. International Federation of Agricultural Producers, 11th conf., New Delhi, India. (IFAP, 1624 Eye St., NW, Washington 6)

28–1. Entomological Soc. of America, Atlantic City, N.J. (R. H. Nelson, 4603 Calvert Rd., College Park, Md.)

29–2. American Medical Assoc., Washington, D.C. (F. Blasinggame, 1535 N. Dearborn St., Chicago 10, Ill.)

30–2. Steels in Reactor Pressure Circuits, symp., London, England. (Secretary, Iron and Steel Inst., 4 Grosvenor Gardens, London, S.W.1)

December

1–16. Commission for Climatology, 3rd session, London, England. (World Meteorological Organization, Campagne Rigot, 1, avenue de la Paix, Geneva, Switzerland)

2–5. Central American Medical Conf., 8th, Panama City. (A. Bissot, Departamento de Saud Publica, Ministerio de Trabajo, Prevision Social y Salud Publica, Panama)

3–6. Visual Communications, 4th annual intern. cong., Chicago, Ill. (Visual Communications Cong., 10600 Puritan Ave., Detroit 38, Mich.)

3–8. American Acad. of Dermatology and Syphilology, Chicago, Ill. (R. R. Kierland, First National Bank Building, Rochester, Minn.)

4–6. Spectroscopy, annual southern seminar, Gainesville, Va. (Annual Seminar on Spectroscopy, Univ. of Florida, Gainesville)

4–7. American Inst. of Chemical Engineers, annual, Washington, D.C. (F. J. Van Antwerpen, AICE, 25 W. 45 St., New York 36)

4–9. Radiological Soc. of North Amer-

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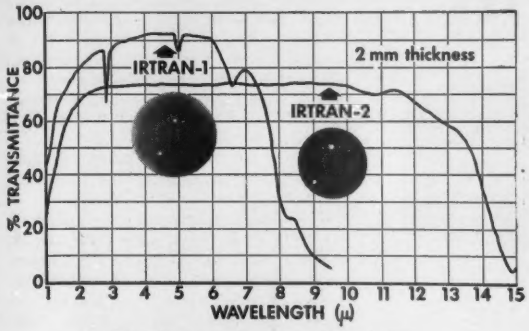

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tan δ = loss tangent
δ is the complement of the vector angle whose cosine the power engineer calls "power factor."

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The ideal radome material would have a kilomegacycle dielectric constant of unity, i.e. to microwaves it would be the same as nothing at all. Plastics commonly used for radomes run around 2 or 3, but they don't transmit infrared rays. On the other hand, there are materials that are good for infrared transmission but have dielectric constant around 13.

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Currently we can supply either of these polycrystalline Irtran *materials as optical elements up to 6½" in diameter, among other forms. Let us have no jurisdictional disputes among optickers, microwavers, and infraredders as to who sends for the supporting data from Eastman Kodak Company, Special Products Division, Rochester 4, N. Y.*

*Formerly designated "Irtran AB-1."

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This book contains more than just pages. Snuggled among them are an actual standard color negative and positive, two special slide-rule computers, and a big nomograph in color about color correction. One of the pages has windows fitted with six different color-print viewing filters. Under the title "Kodak Color Dataguide," it is sold by camera shops for $4.95. (If you send a check to Eastman Kodak Company, Sales Service Division, Rochester 4, N. Y., we shall sigh at how people have forgotten how to walk these days and mail you a copy.)

Frightening as it looks, the book contains virtually no photographic theory. It is a repackaging of operating instructions for two basic categories of users (a better word in this case than "readers"):

1) The professional, be he photographer, scientist, or something in between.

Commercial color labs in many cities do slick work in making color prints or transparencies from exposed film. From Kodacolor or Kodachrome Film, a Kodak dealer would just as soon accept orders to have the work done by Kodak itself as sell a book. But when requirements are too specialized to convey to labs geared for production, the hard way may be the better way.

2) The dedicated amateur who might be painting in oils or water-colors if only he had a better hand for it and who finds that serious color photography brings into play the exact combination of technology and a good eye that best unwinds him from workaday cares.

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ica, Cincinnati, Ohio. (D. S. Childs, 713 E. Genesee St., Syracuse 2, N.Y.)

5–7. American Soc. of Agricultural Engineers, winter, Memphis, Tenn. (J. L. Butt, ASAE, 420 Main St., St. Joseph, Mich.)

5–7. Electronic Industries Assoc., 3rd conf. on maintainability of electronic equipment, San Antonio, Tex. (E. B. Harwood, Office of the Secretary of Defense, Room 3D1018, Pentagon, Washington 25)

5–8. American Rocket Soc., 15th annual, Washington, D.C. (R. L. Hohl, ARS, 500 Fifth Ave., New York 36)

7–13. American Acad. of Optometry, San Francisco, Calif. (C. C. Koch, 1506–08 Foshay Tower, Minneapolis 2, Minn.)

9–10. The Myocardium—Its Biochemistry and Biophysics, New York, N.Y. (A. P. Fishman, New York Heart Assoc., 10 Columbus Circle, New York 19)

9–11. American Psychoanalytic Assoc., New York, N.Y. (D. Beres, 151 Central Park West, New York 23)

10–11. Academy of Psychoanalysis, New York, N.Y. (J. H. Merin, 125 E. 65 St., New York 21)

11–14. Hot Laboratory and Equipment Conf., 8th, San Francisco, Calif. (J. R. Lilienthal, Los Alamos Scientific Laboratory, P.O. Box 1663, Los Alamos, N.M.)

12–14. American Nuclear Soc. (Isotopes and Radiation Div.), San Francisco, Calif. (O. J. Du Temple, ANS, 86 E. Randolph St., Chicago 1, Ill.)

12–14. Water Pollution, natl. conf., Washington, D.C. (Natl. Conf. on Water Pollution, F. A. Butrico, Office of Engineering Resources, Div. of Engineering Services, U.S. Public Health Service, Washington 25)

12–16. Atomic Industrial Forum, conf., San Francisco, Calif. (D. J. Scherer, 3 E. 54 St., New York 22)

13–15. Eastern Joint Computer Conf., New York, N.Y. (E. C. Kubie, EJCC, Computer Usage Co., Inc., 18 E. 41 St., New York 17)

19–20. Statistical Mechanics, conf., London, England. (Organizing Secretary, Physical Soc., 1, Lowther Gardens, London)

22–2. Panamerican Diabetic Congress, 1st, British Honduras. (B. R. Hearst, Director, Diabetic Inst. of America, 55 E. Washington St., Suite 1646, Chicago 2, Ill.)

26–30. Inter-American Cong. of Psychology, 7th, Havana, Cuba. (G. M. Gilbert, Psychology Dept., Long Island Univ., Brooklyn 1, N.Y.)

27. American Astronautical Soc., Lunar Exploration symp., New York, N.Y. (F. F. Martin, AAS, 516 Fifth Ave., New York 36)

27–14. Bahamas Surgical Conf., Nassau. (B. L. Frank, P.O. Box 4037, Fort Lauderdale, Fla.)

28. Association for Education in International Business, St. Louis, Mo. (J. N. Behrman, Univ. of Delaware, Newark, Delaware)

28–30. American Economic Assoc., St. Louis, Mo. (J. W. Bell, Northwestern Univ., Evanston, Ill.)

28–30. Econometric Soc., St. Louis, Mo. (R. Ruggles, Dept. of Economics, Yale Univ., New Haven, Conn.)

28–29. Linguistic Soc. of America, annual, Hartford, Conn. (A. A. Hill, Box 7790, University Station, Austin 12, Tex.)

New Products

The information reported here is obtained from manufacturers and from other sources considered to be reliable. Neither Science *nor the writer assumes responsibility for the accuracy of the information. A coupon for use in mailing inquiries concerning the items listed is included in the post card insert. Circle the department number of the items in which you are interested on this coupon.*

■ GONIOMETER for calibration of divided circles, polygons, and angle gages, provides direct reading to 0.1 sec of arc. The bearing for the worktable carries a glass-divided circle, and the autocollimating telescope unit also contains an optical system for determining the mean value of the opposite-side circle readings. The table may be rotated relative to the divided circle about an auxiliary center by means of a micrometer spindle engaging a worm wheel. A second autocollimating telescope is mounted on a column carried by the base casting. (Engis Equipment Co., Dept. Sci830, 431 S. Dearborn St., Chicago 5, Ill.)

■ REGULATED POWER SUPPLY furnishes independent positive and negative outputs, each capable of being loaded up to 200 ma at 100 volts. The supply uses a Weston cell as voltage reference. Accuracy and stability are said to be better than ±0.1 percent, long term, for −100 volts. The +100-volt supply can be set to within 1 mv of the negative supply voltage and will remain within 5 mv. Source impedance is less than 0.05 ohm and ripple and noise are less than 15 mv peak-to-peak. (Solartron Electronic Group, Dept. Sci832, Thames Ditton, Surrey, England)

■ BLOOD FLOW METER for use during cardiopulmonary bypass is based on the electromagnetic induction principle. The meter is a refinement of the manufacturer's industrial magnetic flow meter. An indicator provides continuous flow indication, an integrator totalizes liters of blood flow during bypass, and a chart record permits postoperative evaluation. Standard range is 0 to 5 lit./min. Accuracy is said to be ±1 percent of full scale over the entire scale and repeatability ±0.5 percent of full scale. The flow tube is removable from the meter for sterilization. (Foxboro Co., Dept. Sci838, Foxboro, Mass.)

■ SEMICONDUCTOR DEVICE TESTER will test transistors for breakdown voltage, gain over the complete dynamic range, voltage and current saturation characteristics, and leakage current at up to 80 volts. Zener diodes can be tested for breakdown voltage, dynamic impedance at any current up to 1 amp, and drift with temperature or current. Rectifiers can be tested for leakage up to 80 volts and forward-current char-

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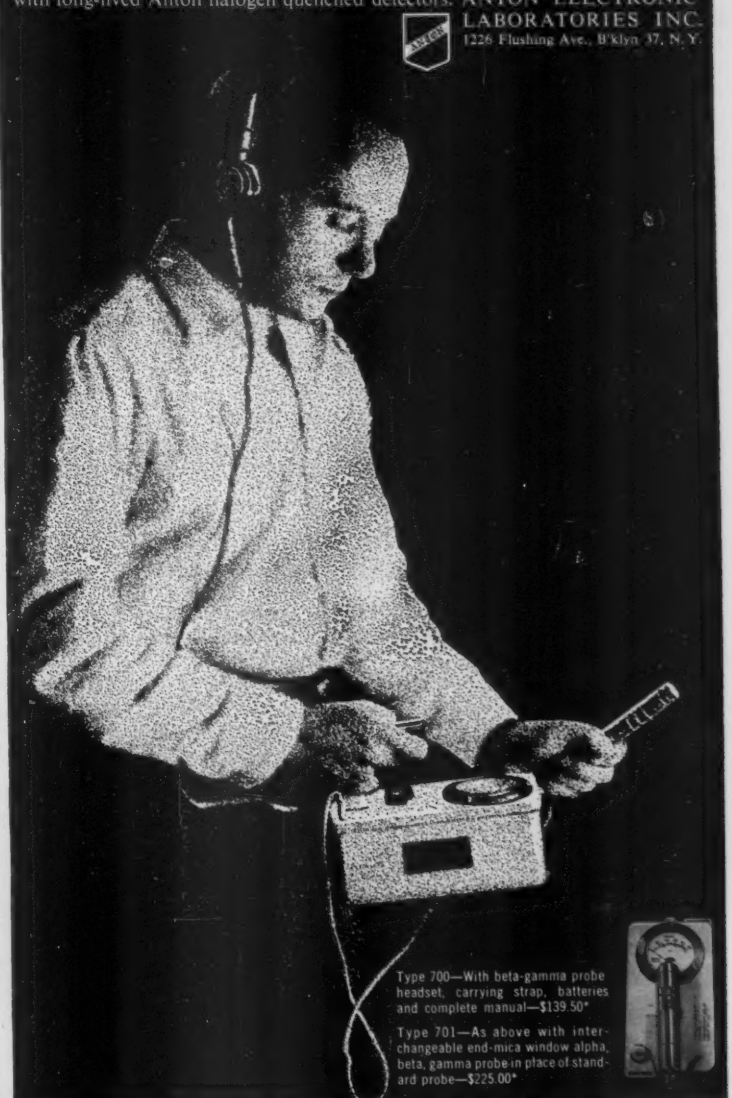

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acteristics up to 1 amp. Tunnel-diode characteristics of tunneling current, valley current, and forward voltage can be determined. (PRL Corporation, Dept. Sci833, P.O. Box 215, East Brunswick, N.J.)

■ PRESSURE BALANCE for calibration of pressure gages provides a pressure range from 1000 to 48,000 lb/in.^{2} in 94 steps of 500 lb/in.^{2}, or 50 to 3250 atm in 128 steps of 25 atm. Accuracy is said to be 1 part in 2000. Balance weights are lifted mechanically by a series of levers that permit selection of any combination without stopping the balancing operation. (High Pressure Equipment Co., Dept. Sci843, 1222 Linden Ave., Erie, Pa.)

■ LEAD SULFIDE PHOTOCONDUCTORS are Dewar-mounted for operation from room temperature to −196°C. The detecting elements consist of chemically deposited lead-sulfide films with response to 4.5 μ. Specifications quoted are: dark resistance, 0.5 to 5 megohm/square; time constant, 800 to 2000 μsec. A variety of Dewar designs, cell configurations, and immersions is available. All are furnished with fire-sealed, sapphire windows. (Infrared Industries, Inc., Dept. Sci845, P.O. Box 42, Waltham 54, Mass.)

■ PRECISE LINEAR SCALES are offered in two types. Type A, available in 150-, 250-, and 500-mm graduated lengths, produced by direct ruling, is said to be accurate to ±0.75 μ. Lines are engraved and etched in glass. Type B, available in 150- and 200-mm graduated lengths, is produced photographically with accuracy said to be ±2.5 μ. English graduations are also available. (David W. Mann Co., Dept. Sci851, Lincoln, Mass.)

■ RECORDING INSTRUMENT times short-duration events to milliseconds even at slow chart speeds. Time markings along edge of the chart show time of day any event occurs while sweep of the recording pen across the chart displays duration of the event. Sweep-time scale ranges from 1 sec to 1 hr are available. Standard chart speeds are ¾, 1½, 3, 6, and 12 in./hr and in./min. (R. B. Annis Co., Dept. Sci850, 1101 N. Delaware St., Indianapolis 2, Ind.)

■ COUNT-RATE AND PERIOD METER is a logarithmic instrument that measures neutron count/min over a six-decade range from 10 to 10^6 count/min. The output reading is available for remote meter and recorder connections. The instrument also provides continuous indication of rate of change of power level during reactor startup and trips an alarm if the reactor period is shorter than a preset interval. (General Electric Co., Dept. Sci852, Schenectady 5, N.Y.)

■ X-RAY FLUORESCENCE SPECTROMETER uses an evacuated chamber so that all elements of atomic number above 11 can be analyzed without use of helium atmosphere. Simultaneous analysis of the elements is said to be obtained in about 2 min. Dual sample handling facilities permit sample interchange without breaking vacuum. (Applied Research Laboratory, Dept. Sci853, P.O. Box 1710, Glendale 5, Calif.)

■ PRESSURE REFERENCE CELL consists of a pressure storage chamber, a diaphragm, and a sensitive switch. The cell detects equality between an unknown pressure and the reference pressure. Stored pressure ranges from 0.2 to 200 in.-Hg. Cells can be furnished sealed at a given pressure or unsealed. Temperature dependence is about 0.35 percent/°C and the units must be operated in an ice bath for best performance according to the manufacturer. Precision is said to be ±(0.001 in.-Hg. + 0.003 percent of calibrated value). Multiple gage calibration is accomplished by manifolding a series of cells and the gages to be calibrated. (Rosemount Engineering Co., Dept. Sci854, 4900 W. 78 St., Minneapolis, Minn.)

■ SIGNAL GENERATOR covers the frequency range .1 cy to 1 Mcy/sec. Distortion is said to be 0.2 percent. An output meter and attenuator permit output amplitude to be set to desired value. (Southwestern Industrial Electronics Co., Dept. Sci839, 10201 Westheimer Rd., Houston 27, Tex.)

■ DECADE RING COUNTER consists of ten magnetic storage elements connected as a ring counter. Pulses furnished to an input terminal are stored by shifting them along from position to position in the forward mode of operation. Upon receipt of a command signal on a separate "reverse" line, counts are subtracted instead of being added. Decades may be cascaded. Counting rates up to 10^6/sec are accommodated. Reversal time is 10 μsec. (Magnetics Research Co., Dept. Sci855, 255 Grove St., White Plains, N.Y.)

■ TIME ANALYZER is an electronic instrument that resolves a time span into up to 40 consecutive intervals and analyzes input events in terms of the number of occurrences within each interval. Duration of the intervals is variable over a wide range. Connection to an appropriate recorder pro-

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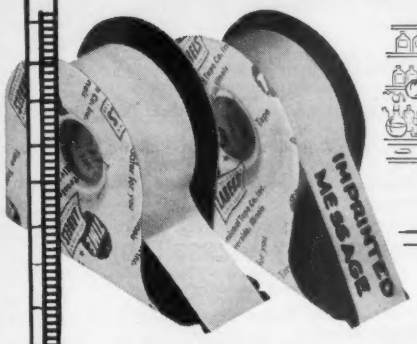

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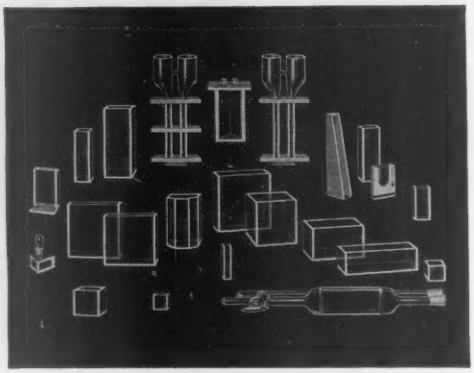

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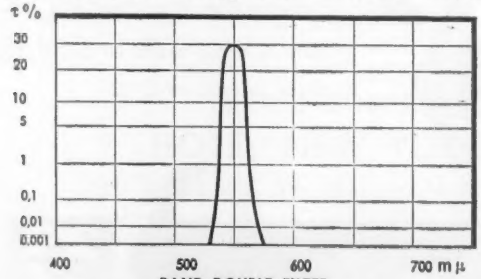

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■ PULSE GENERATOR produces positive or negative pulses of amplitude up to 20 volts. Line changes between 90 and 125 volts change output amplitude less than 0.04 percent. Two pulse shapes are provided, one with 10 mμsec rise and 250 μsec decay, the other with 0.25 μsec rise and 2 μsec decay. Linearity is 0.1 percent. Voltage ranges from 0 to 20, 0 to 10, 0 to 1, 0 to 0.1 and 0.01 can be divided into 1000 increments by means of a ten-turn precision potentiometer. (Interstate Electronics Corp., Dept. Sci847, 707 E. Vermont Ave., Anaheim, Calif.)

■ VIBRATING-REED CAPACITANCE MODULATOR is said to permit measurement of currents as low as 10^{-16} amp. The vibrating plate is driven by an alternating magnetic field. Drift is said to be within ± 0.2 mv/day. Models are available with quartz or with ceramic insulation and with 500 or 120 cy/sec drive frequency. (Stevens-Arnold Inc., Dept. Sci844, 7 Elkins St., South Boston 27, Mass.)

■ NOISE SOURCE furnishes output frequencies over the range 30 cy to 300 kcy/sec with uniformity to ± 2 db when used with the proper amplifier circuits. No a-c power is used. Output voltage is 0 to 10 mv r.m.s. into a 1000-ohm load. The device is transistorized; its dimensions are 1½ in. square by 3 in. (Raytheon Co., Dept. Sci848, 55 Chapel St., Newton, Mass.)

■ DOUBLE SCALER provides two scales of 10^4 each followed by a four-digit electrically reset register. The two sections may be operated individually or simultaneously. Resolving time is said to be 0.8 μsec. Provision is made for remote control of count and reset operations. (Radiation Instrument Development Laboratory, Dept. Sci856, 61 E. North Ave., Northlake, Ill.)

■ VELOCITY SERVO accepts d-c signals varying between ± 10 volts and drives a potentiometer so that speed is directly proportional to the d-c signal. The device contains a solid-state amplifier, a servo motor, a gear train, and a potentiometer-switch combination. The potentiometer has four electrically isolated wipers spaced 90 deg apart and the switch has four wipers riding on an alternately conducting and nonconducting surface. Dimensions are 1½ by 1½ by 3 in. (Spectrol Electronics Corp., Dept. Sci862, 1704 S. Del Mar Ave., San Gabriel, Calif.)

■ CARDIAC PHONOCATHETERS are available in two models. Model 191 is a single-lumen phonocatheter, 150 cm long and 2 mm in diameter, for acoustical pickup only. Model 192 is a double-lumen catheter, 150 cm long and 3 mm in diameter, for acoustical and pressure pickup and for fluid samples. Base diameter of the sample lumen is approximately 1 mm. A self-powered preamplifier that will feed standard electrocardiographic equipment is available for use with the catheters. (American Electronic Laboratories, Dept. Sci857, 121 N. 7 St., Philadelphia 6, Pa.)

■ X-RAY SOURCE uses an active element, Sr^{90}/Y^{90}, distributed in a matrix of target material to maximize x-ray production in the desired range. The unit is in the form of a stainless-steel capsule doubly sealed by shielded arc welding. X-rays produced are in the 100-kv range. (U.S. Nuclear Corp., Dept. Sci865, P.O. Box 208, Burbank, Calif.)

■ TRANSFER-FUNCTION ANALYZER permits plotting of transfer characteristics of a control system with a conventional *X-Y* recorder. By turning the dial of the instrument, continuous plotting of

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■ STEREOSCOPIC TELEVISION SYSTEM consists of two closed-circuit television cameras, two monitors, two camera control units, and a polarized optical system. The optical system presents the overlapping images from each camera on a single viewing plane with one image polarized horizontally and the other polarized vertically. Observation through glasses or a viewing hood provides three-dimensional picture presentation. The standard system employs 14-in. monitors but other sizes from 8 to 27 in. can be supplied. (Cohu Electronics, Inc., Dept. Sci867, 5725 Kearny Villa Rd., San Diego 11, Calif.)

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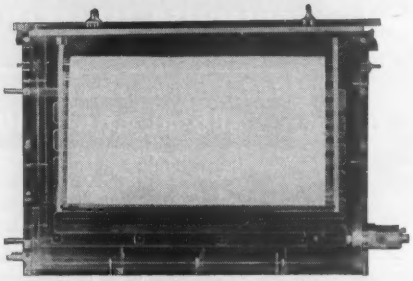

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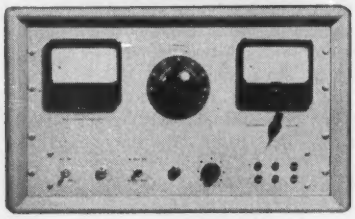

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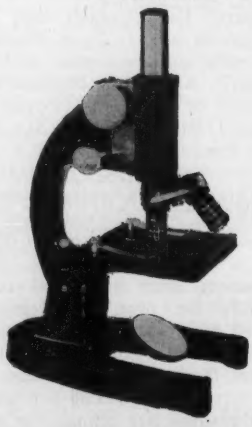

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Classified in the following pages are the products advertised in *Science* in the issues from 2 October 1959 through 7 October 1960. This list is intended to aid laboratory workers in finding the manufacturers of all types of laboratory equipment and supplies. On page 1202 there is a list of companies that advertised in "The Market Place" section during the period 2 October 1959 through 7 October 1960. An index of advertisers in this issue appears on page 1204.

ABSORPTION CELLS

Beckman Instruments, Inc., Scientific and Process Instruments Div.
1960: 4 Mar., 628; 15 Apr., 1068; 29 July, 305
Klett Manufacturing Co.
1959: 2 Oct., 867; 9 Oct., 931; 16 Oct., 988; 30 Oct., 1202; 6 Nov., 1269; 13 Nov., 1347; 27 Nov., 1486; 11 Dec., 1665
1960: 8 Jan., 115; 15 Jan., 165; 22 Jan., 243; 5 Feb., 368; 12 Feb., 425; 19 Feb., 545; 26 Feb., 618; 4 Mar., 676; 18 Mar., 843; 1 Apr., 997; 29 Apr., 1325; 13 May, 1452; 20 May, 1552; 27 May, 1626; 10 June, 1746; 24 June, 1896; 1 July, 47; 15 July, 159; 22 July, 254; 29 July, 305; 5 Aug., 369; 19 Aug., 477; 9 Sept., 686; 16 Sept., 747; 23 Sept., 850; 30 Sept., 905

ACCELERATORS, VAN DE GRAFF

High Voltage Engineering Corp.
1960: 29 Apr., 1284; 20 May, 1490

AIR POLLUTION DETECTION UNIT

Central Scientific Co.
1960: 9 Sept., 684

AMPLIFIERS

American Electronic Laboratories, Inc.
1959: 4 Dec., 1581
1960: 22 Jan., 233; 18 Mar., 778; 22 Apr., 1226
Beckman Instruments, Inc., Scientific and Process Instruments Div.
1960: 9 Sept., 683
Sanborn Co., Medical Div.
1960: 5 Feb., 371
Radiation Instrument Development Laboratory, Inc.
1960: 23 Sept., 847
Technical Associates
1960: 22 July, 247

ANALYZERS

Beckman Instruments, Inc., Scientific and Process Instruments Div.
1959: 6 Nov., 1212
1960: 1 Jan., 4; 19 Feb., 453; 18 Mar., 785; 20 May, 1471
Central Scientific Co.
1960: 27 May, 1626; 7 Oct., 973
Coleman Instruments, Inc.
1960: 19 Feb., 462; 18 Mar., 765; 29 Apr., 1281; 23 Sept., 766
Fisher Scientific Co.
1959: 13 Nov., 1350
Harvard Apparatus Co., Inc.
1959: 4 Dec., 1605
Packard Instrument Co., Inc.
1959: 23 Oct., 1041; 11 Dec., 1628
1960: 22 Jan., 196; 19 Feb., 478
Philips Electronics, Inc.
1959: 9 Oct., 884
Scientific Glass Apparatus Co., Inc.
1960: 24 June, 1895

ANALYZERS, PULSE HEIGHT

Picker X-Ray Corp.
1960: 22 Apr., 1151; 15 July, 107; 23 Sept., 775
Radiation Instrument Development Laboratory, Inc.
1960: 19 Feb., 473; 23 Sept., 847; 7 Oct., 964
Technical Associates
1960: 18 Mar., 865; 20 May, 1563; 22 July, 247
Technical Measurement Corp.
1959: 9 Oct., 894; 23 Oct., 1048; 20 Nov., 1380; 4 Dec., 1532
1960: 8 Jan., 70; 4 Mar., 632; 22 Apr., 1162; 17 June, 1778; 15 July, 112; 26 Aug., 516; 7 Oct., 922
Victoreen Instrument Co.
1960: 17 June, 1755

ANIMALS, EXPERIMENTAL

Charles River Breeding Laboratories, Inc.
1960: 7 Oct., 973, 974
Colorado Serum Co.
1959: 23 Oct., 1132; 13 Nov., 1363; 4 Dec., 1597
1960: 15 Jan., 165; 19 Feb., 537; 18 Mar., 857; 22 Apr., 1226; 9 Sept., 681

AUTOCLAVES

American Sterilizer Co.
1960: 19 Feb., 443
Wilmot Castle Co.
1960: 22 Apr., 1134; 17 June, 1762

BALANCES, ANALYTICAL

Brinkmann Instruments, Inc.
1959: 23 Oct., 1141
1960: 16 Sept., 751; 23 Sept., 770; 30 Sept., 905; 7 Oct., 917
Central Scientific Co.
1960: 22 Jan., 232; 29 Apr., 1325; 19 Aug., 489; 9 Sept., 680
Exact Weight Scale Co.
1959: 23 Oct., 1111
1960: 19 Feb., 535; 18 Mar., 841; 22 Apr., 1233; 17 June, 1817; 26 Aug., 566
Harshaw Chemical Co.
1960: 29 Apr., 1326; 8 July, 96; 16 Sept., 746
Mettler Instrument Corp.
1959: 23 Oct., 1022; 4 Dec., 1586
1960: 19 Feb., 456; 18 Mar., 779; 20 May, 1484; 23 Sept., 776
Microtech Services Co.
1959: 2 Oct., 872
New York Laboratory Supply Co., Inc.
1960: 22 Apr., 1241

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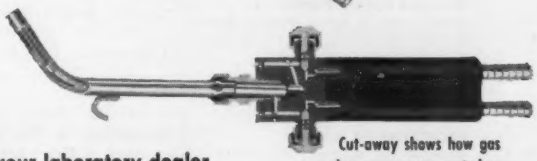

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Standard Scientific Supply Corp.
1959: 23 Oct., 1128
Stoelting, C. H., Co.
1960: 22 July, 245; 26 Aug., 563
Torsion Balance Co.
1959: 23 Oct., 1019
1960: 19 Feb., 463; 22 Apr., 1143; 20 May, 1474; 22 July, 181; 26 Aug., 515
Welch, W. M., Manufacturing Co.
1960: 5 Feb., 367

BALANCES, ANIMAL

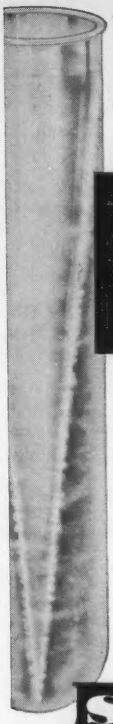
Exact Weight Scale Co.
1959: 23 Oct., 1111
1960: 19 Feb., 535; 18 Mar., 841; 22 Apr., 1233; 17 June, 1817; 26 Aug., 566

BEAKERS

LaPine, Arthur S., and Co.,
1960: 20 May, 1550
Nalge Co., Inc.
1960: 20 May, 1564; 17 June, 1824; 22 July, 248

BOOKS AND JOURNALS

Academic Press
1960: 22 Apr., 1230
Addison-Wesley Publishing Co., Inc.
1960: 22 Apr., 1240
Annual Reviews, Inc.
1959: 2 Oct., 872; 23 Oct., 1121; 6 Nov., 1271; 4 Dec., 1589
1960: 8 Jan., 117; 19 Feb., 531; 18 Mar., 844; 22 Apr., 1243; 13 May, 1457; 17 June, 1823; 22 July, 233; 5 Aug., 369; 2 Sept., 627; 7 Oct., 972
ARTIA, Prague, Czechoslovakia
1960: 15 July, 159
Baker, J. T., Chemical Co.
1960: 12 Feb., 428
Basic Books
1959: 16 Oct., 985
1960: 19 Feb., 528; 22 Apr., 1246; 7 Oct., 916
British Information Services
1959: 23 Oct., 1126; 4 Dec., 1594
1960: 19 Feb., 552
Burgess Publishing Co.
1960: 22 Apr., 1226; 22 July, 254; 26 Aug., 571
California Academy of Sciences
1960: 19 Feb., 533
Cambridge University Press
1960: 22 Apr., 1222
Cattell, Jaques, Press, Inc.
1960: 25 Mar., 943
Consultants Bureau Enterprises, Inc.
1960: 22 Apr., 1123; 15 July, 157
Daedalus
1960: 23 Sept., 836; 7 Oct., 971
Doubleday & Co., Inc.
1960: 5 Feb., 326; 19 Feb., 447; 3 June, 1683
Dover Publications, Inc.
1959: 30 Oct., 1160
1960: 29 Jan., 262; 29 Apr., 1280
Dutton, E. P., & Co.
1960: 2 Sept., 626
Eaton-Dikeman Co.
1960: 20 May, 1562
Edmund Scientific Co.
1960: 26 Aug., 508; 23 Sept., 855



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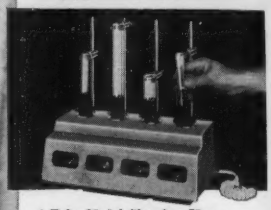

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Fisher Verlag
1960: 22 Apr., 1221
Greiner, Emil, Co.
1960: 22 Jan., 249; 26 Aug., 568
Grune & Stratton
1959: 27 Nov., 1485
Harvard University Press
1959: 20 Nov., 1434
1960: 5 Feb., 366; 22 Apr., 1266; 26 Aug., 565
Holt, Henry, and Co., Inc.
1960: 22 Apr., 1224
Interscience Publishers, Inc.
1959: 13 Nov., 1357
Johns Hopkins Press
1960: 22 Apr., 1251
Kling Photo Corp.
1960: 23 Sept., 834
Lea & Febiger
1959: 4 Dec., 1585
1960: 22 Apr., 1161
Library of Science
1959: 13 Nov., 1289
1960: 11 Mar., 691
Lippincott, J. B., Co.
1960: 22 Jan., 234; 22 Apr., 1252
Long Island Biological Assoc.
1959: 13 Nov., 1361
Macmillan Co.
1960: 22 Apr., 1264; 10 June, 1744
Macy, Josiah, Jr., Foundation
1959: 16 Oct., 993
Martineau, Paul
1960: 13 May, 1455
McGraw-Hill Book Co., Inc.
1960: 22 Apr., 1132, 1133; 26 Aug., 495
Merck & Co., Inc.
1959: 13 Nov., 1348
1960: 17 June, 1820
Mistaire Laboratories
1959: 27 Nov., 1489; 4 Dec., 1608; 11 Dec., 1660; 18 Dec., 1714
Mosby, C. V., Co.
1960: 22 Apr., 1157
Oxford University Press
1959: 4 Dec., 1598
1960: 19 Feb., 546; 8 Apr., 1053; 9 Sept., 682; 7 Oct., 968
Pergamon Press, Inc.
1959: 23 Oct., 1149
1960: 18 Mar., 877; 22 Apr., 1139
Philosophical Library
1959: 2 Oct., 871; 20 Nov., 1433; 27 Nov., 1487
1960: 22 Apr., 1239
Pioneer Scientific Corp.
1960: 16 Sept., 703
Prentice-Hall, Inc.
1960: 22 Apr., 1127, 1141
Princeton University Press
1960: 22 Apr., 1248
Putnam's, G. P., Sons
1960: 4 Mar., 677
Random House
1960: 25 Mar., 940
Reinhold College Textbook Department
1960: 22 Apr., 1129
Rockefeller Institute Press
1959: 4 Dec., 1595
Ronald Press Co.
1960: 8 Jan., 66; 19 Feb., 548; 22 Apr., 1232; 19 Aug., 483
Saunders, W. B., Co.
1959: 9 Oct., 879; 6 Nov., 1211; 4 Dec., 1495
1960: 1 Jan., 3; 12 Feb., 375; 11 Mar., 685; 1 Apr., 955; 8 Apr., 1003; 15 Apr., 1070; 22 Apr., 1115; 29 Apr., 1283; 6 May, 1335; 13 May, 1398; 20 May, 1463;

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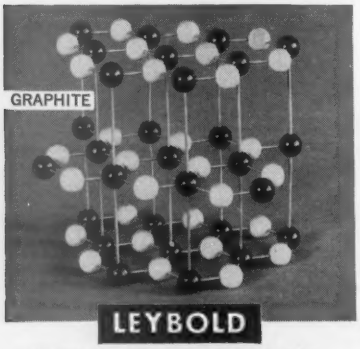

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3 June, 1635; 1 July, 3; 12 Aug., 375; 9 Sept., 635; 7 Oct., 911

Schaar and Co.
1960: 20 May, 1557

Science Book Club, Inc.
1959: 9 Oct., 885

Society for General Systems Research
1960: 19 Feb., 539

Springer Verlag
1960: 29 Apr., 1278; 1 July, 4; 22 July, 245; 30 Sept., 905

United Nations
1960: 22 Apr., 1228

University of California Press
1960: 23 Sept., 827

University of Chicago Press
1959: 4 Dec., 1524
1960: 6 May, 1387; 8 July, 99

University of Michigan Press
1960: 29 Jan., 311; 22 Apr., 1131

University of Wisconsin Press
1959: 23 Oct., 1132
1960: 22 Apr., 1145

Van Nostrand, D., Co., Inc.
1959: 23 Oct., 1151
1960: 22 Apr., 1135; 7 Oct., 921

Welch, W. M., Manufacturing Co.
1960: 1 Jan., 51

Wiley, John, & Sons, Inc.
1959: 9 Oct., 888; 4 Dec., 1516, 1517
1960: 12 Feb., 431; 11 Mar., 688; 22 Apr., 1118, 1119

Williams & Wilkins Co.
1960: 22 Apr., 1153

Yale University Press
1960: 1 July, 47

Year Book Publishers, Inc.
1960: 11 Mar., 693; 22 Apr., 1235

BORESCOPES

American Cystoscope Makers, Inc.
1960: 23 Sept., 821

BRAIN STIMULATION EQUIPMENT

Foringer & Co., Inc.
1960: 7 Oct., 971

BURNERS

Standard Scientific Supply Corp.
1959: 13 Nov., 1360
1960: 19 Feb., 538

CAGES, ANIMAL

Brunswick Corp., Aloe Scientific Div.
1960: 26 Aug., 553; 23 Sept., 835

Kirschner Manufacturing Co.
1960: 19 Feb., 531; 22 Apr., 1231; 23 Sept., 830

Labline, Inc.
1959: 4 Dec., 1599

Maryland Plastics, Inc., Econo-Cage Div.
1959: 23 Oct., 1147
1960: 22 Jan., 239; 19 Feb., 543; 22 Apr., 1249; 29 Apr., 1328; 17 June, 1831; 23 Sept., 764

Will Corp.
1959: 4 Dec., 1513

CALORIMETERS

Parr Instrument Co.
1960: 18 Mar., 870

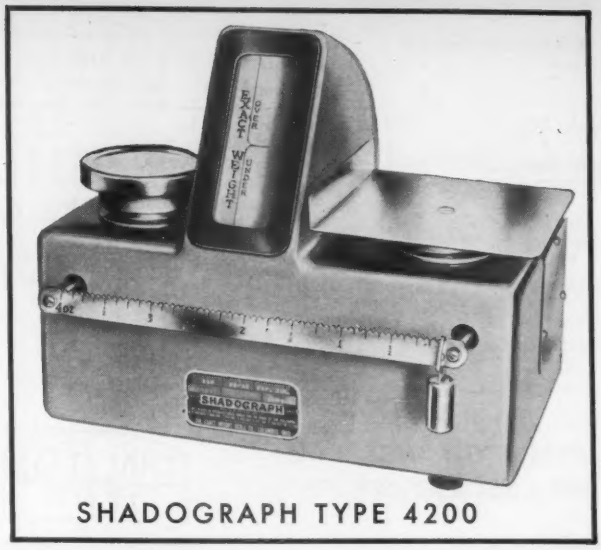
CAMERAS AND ACCESSORIES

Aloe, A. S., Co., Aloe Scientific Div.
1959: 6 Nov., 1271

American Optical Co.
1959: 6 Nov., 1276
1960: 15 Jan., 172; 22 Apr., 1272; 15 July, 164
Avco Corp., Research and Advanced Development Div.
1959: 23 Oct., 1017
Beckman & Whitley
1959: 23 Oct., 1011
1960: 19 Feb., 569
Kling Photo Corp.
1960: 17 June, 1820; 22 July, 230; 26 Aug., 556
Philips Electronics, Inc.
1959: 13 Nov., 1284, 1285
Rosenthal, Paul
1960: June, 1744; 23 Sept., 822
United Scientific Co.
1959: 23 Oct., 1076, 1077
1960: 19 Feb., 436; 27 May, 1576; 19 Aug., 436

CATALOGS

Ace Glass, Inc.
1960: 22 Jan., 247; 20 May, 1547; 22 July, 237
Baird-Atomic Inc.
1960: 19 Feb., 468
Baker, J. T., Chemical Co.
1959: 4 Dec., 1503
1960: 8 Jan., 65; 18 Mar., 767
Bausch & Lomb Optical Co.
1959: 9 Oct., 896; 6 Nov., 1224; 20 Nov., 1382; 4 Dec., 1534
1960: 29 Jan., 268; 11 Mar., 698; 18 Mar., 772, 773; 25 Mar., 896; 8 Apr., 1014; 22 Apr., 1164; 6 May, 1340; 13 May, 1453; 20 May, 1492; 3 June, 1640; 17 June, 1780; 1 July, 8; 12 Aug., 386; 19 Aug., 479; 23 Sept., 784; 7 Oct., 924
Beckman Instruments, Inc., Scientific and Process Instruments Div.
1960: 4 Mar., 628; 15 Apr., 1068; 29 July, 305
Bel-Art Products
1960: 19 Feb., 555
Brinkmann, C. A., & Co.
1960: 22 Jan., 216, 217, 218; 5 Feb., 361; 26 Feb., 613; 8 Apr., 1004; 20 May, 1549; 3 June, 1685
Corning Glass Works
1959: 9 Oct., 891
1960: 22 Jan., 249; 5 Feb., 323; 11 Mar., 745; 8 Apr., 1011; 13 May, 1450; 3 June, 1636
Colorado Serum Co.
1959: 13 Nov., 1363
1960: 19 Feb., 537; 18 Mar., 857; 22 Apr., 1226
Duralab Equipment Corp.
1960: 18 Mar., 881
Edmund Scientific Co.
1959: 6 Nov., 1221
1960: 18 Mar., 791; 27 May, 1631; 17 June, 1764
Esterline-Angus Co.
1960: 22 July, 250
Falcon Plastics Co.
1959: 23 Oct., 1035
Fisher Scientific Co.
1960: 22 Jan., 189
Greiner, Emil, Co.
1960: 22 Jan., 249
Harvard Apparatus Co., Inc.
1959: 4 Dec., 1605
1960: 22 Apr., 1261
Industrial Instruments, Inc.
1960: 22 Jan., 244; 18 Mar., 846; 22 Apr., 1232; 17 June, 1816



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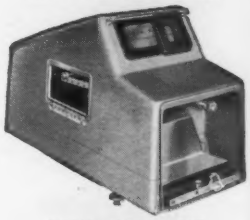
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Instruments for Research and Industry
1960: 18 Mar., 878
Kimble Glass Co.
1960: 15 Jan., 123; 22 Jan., 183; 12 Feb., 381; 11 Mar., 689; 15 Apr., 1072; 13 May, 1399
Kewaunee Scientific Equipment
1960: 19 Feb., 536
Lafayette Radio
1959: 23 Oct., 1013
Lourdes Instrument Corp.
1960: 18 Mar., 783
Matheson Co., Matheson Coleman & Bell Div.
1960: 20 May, 1565
Microchemical Specialties Co.
1960: 22 Apr., 1222
Nalge Co., Inc.
1960: 19 Feb., 532; 18 Mar., 872; 1 Apr., 995; 22 Apr., 1227; 20 May, 1564; 17 June, 1824; 22 July, 248; 26 Aug., 570; 23 Sept., 824
National Appliance Co.
1959: 23 Oct., 1118
1960: 8 Jan., 111; 4 Mar., 674
New Brunswick Scientific Co., Inc.
1960: 15 Jan., 165; 22 Jan., 255; 19 Feb., 559; 26 Feb., 619; 18 Mar., 877; 25 Mar., 943; 22 Apr., 1235; 27 May, 1626; 10 June, 1747; 17 June, 1838; 24 June, 1896
Nuclear-Chicago Corp.
1959: 16 Oct., 996
1960: 1 Apr., 1000
Nuclear Corporation of America, Isotopes Specialties Co.
1960: 26 Aug., 577
Nutritional Biochemicals Corp.
1959: 30 Oct., 1159; 13 Nov., 1279; 27 Nov., 1443; 11 Dec., 1615
1960: 8 Jan., 55; 22 Jan., 175; 5 Feb., 315; 19 Feb., 435; 4 Mar., 625; 18 Mar., 753; 1 Apr., 951; 15 Apr., 1063; 29 Apr., 1275; 13 May, 1395; 27 May, 1575; 10 June, 1695; 24 June, 1851; 8 July, 55; 22 July, 167; 5 Aug., 315; 19 Aug., 435; 2 Sept., 583; 16 Sept., 695; 30 Sept., 859
Pioneer Scientific Corp., subsidiary of Bausch & Lomb Optical Co.
1960: 16 Sept., 703
Radiochemical Centre
1960: 8 Jan., 115; 5 Feb., 361; 29 Apr., 1325; 24 June, 1893; 22 July, 249
Sanborn Co., Medical Div.
1959: 16 Oct., 983; 11 Dec., 1623
Schueler & Co., Schuco Scientific Div.
1960: 23 Sept., 814
Sorensen & Co. Inc.
1960: 22 Apr., 1223; 20 May, 1468; 23 Sept., 841
Sorvall, Ivan, Inc.
1960: 17 June, 1760, 1761; 23 Sept., 773
Technical Associates
1960: 18 Mar., 865
United Scientific Co.
1959: 2 Oct., 871; 30 Oct., 1201; 6 Nov., 1266; 27 Nov., 1484; 4 Dec., 1584
1960: 8 Jan., 114; 15 Jan., 168; 29 Jan., 304; 26 Feb., 616; 4 Mar., 677; 25 Mar., 940; 1 Apr., 996; 8 Apr., 1054; 22 Apr., 1246; 6 May, 1388; 13 May, 1454; 20 May, 1562; 27 May, 1576; 3 June, 1688; 17 June, 1840; 24 June, 1852; 8 July, 98; 15 July, 156; 5 Aug., 364; 12 Aug., 427; 2 Sept., 626; 9 Sept., 683; 16 Sept., 748; 30 Sept., 902; 7 Oct., 970
Welch, W. M., Manufacturing Co.
1960: 4 Mar., 675; 7 Oct., 967
Will Corp.
1959: 23 Oct., 1127

CELLS

Beckman Instruments, Inc., Scientific and Instruments Process Div.
1960: 4 Mar., 628; 15 Apr., 1068; 29 July, 305

CENTRIFUGES AND ACCESSORIES

Beckman Instruments, Inc., Spinco Div.
1959: 9 Oct., 878; 23 Oct., 999; 25 Dec., 1727
1960: 26 Feb., 572; 25 Mar., 890; 27 May, 1574; 24 June, 1850; 26 Aug., 494; 23 Sept., 754
Corning Glass Works
1960: 8 Apr., 1011
Custom Scientific Instruments, Inc.
1959: 23 Oct., 1142
1960: 22 Jan., 234; 22 July, 236; 23 Sept., 834
Doerr Glass Co.
1959: 13 Nov., 1283; 4 Dec., 1499
International Equipment Co.
1959: 2 Oct., 875; 16 Oct., 940; 23 Oct., 1007; 13 Nov., 1299; 27 Nov., 1483; 4 Dec., 1510; 25 Dec., 1730, 1731
1960: 8 Jan., 67; 5 Feb., 318, 319; 19 Feb., 471; 4 Mar., 626; 18 Mar., 797; 8 Apr., 1009; 22 Apr., 1154, 1155; 13 May, 1401; 27 May, 1579; 10 June, 1751; 24 June, 1855; 8 July, 103; 22 July, 175; 5

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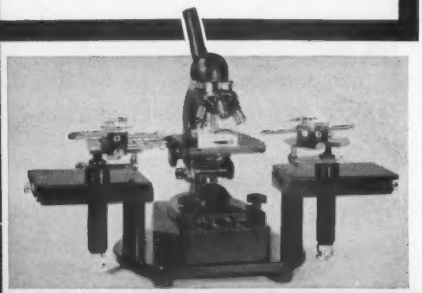

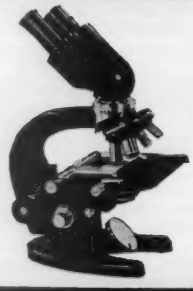

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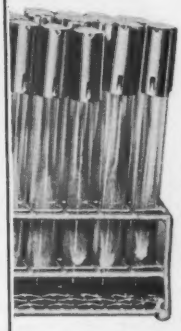

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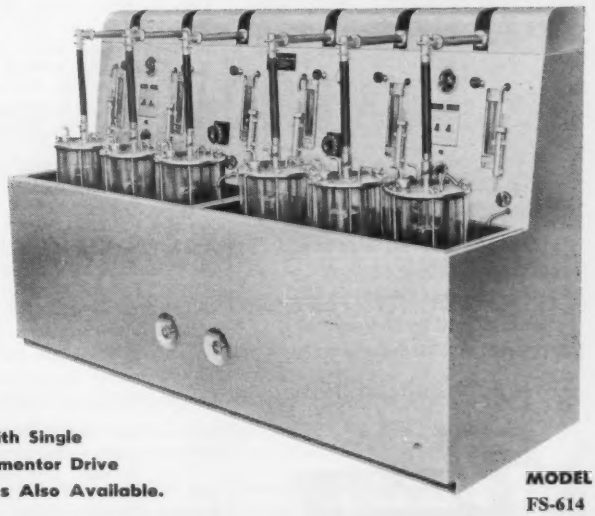

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Aug., 319; 19 Aug., 438; 2 Sept., 587; 30 Sept., 860

Lourdes Instrument Corp.
1959: 23 Oct., 1014
1960: 22 Jan., 182; 19 Feb., 441; 18 Mar., 783; 22 Apr., 1149; 23 Sept., 819; 7 Oct., 969

Sorvall, Ivan, Inc.
1959: 23 Oct., 1024, 1025; 13 Nov., 1371; 4 Dec., 1509
1960: 19 Feb., 444, 445; 18 Mar., 756, 757; 20 May, 1561; 17 June, 1760, 1761; 22 July, 231; 26 Aug., 567; 23 Sept., 773

CHEMICALS, BIOLOGICAL

Borden Chemical Co.
1959: 23 Oct., 1142

Difco Laboratories
1959: 13 Nov., 1351
1960: 22 Apr., 1221; 26 Aug., 563

Matheson Co., Inc., Matheson Coleman & Bell Div.
1960: 20 May, 1565

Merck & Co., Inc.
1959: 13 Nov., 1348

New England Nuclear Corp.
1959: 20 Nov., 1432

Nutritional Biochemicals Corp.
1959: 2 Oct., 819; 16 Oct., 939; 30 Oct., 1159; 13 Nov., 1279; 27 Nov., 1443; 11 Dec., 1615; 25 Dec., 1727
1960: 8 Jan., 55; 22 Jan., 175; 5 Feb., 315; 19 Feb., 435; 4 Mar., 625; 18 Mar., 753; 1 Apr., 951; 15 Apr., 1063; 29 Apr., 1275; 13 May, 1395; 27 May, 1575; 10 June, 1695; 24 June, 1851; 8 July, 55; 22 July, 167; 5 Aug., 315; 19 Aug., 435; 2 Sept., 583; 16 Sept., 695; 30 Sept., 859

Schwarz BioResearch, Inc.
1959: 9 Oct., 880; 13 Nov., 1300
1960: 22 Jan., 179; 5 Feb., 363; 18 Mar., 786; 20 May, 1482; 10 June, 1745; 22 July, 172; 29 July, 307; 23 Sept., 779

Sigma Chemical Co.
1959: 6 Nov., 1269; 4 Dec., 1591
1960: 1 Jan., 47; 29 Jan., 305; 26 Feb., 617; 25 Mar., 941; 20 May, 1545; 17 June, 1823; 15 July, 159; 23 Sept., 843

Will Corp.
1960: 20 May, 1516, 1517

Winthrop Laboratories
1959: 23 Oct., 1116
1960: 12 Feb., 425; 18 Mar., 843; 22 Apr., 1251; 27 May, 1628; 16 Sept., 749

Worthington Biochemical Corp.
1960: 1 Jan., 48; 5 Feb., 364; 4 Mar., 630; 1 Apr., 994; 20 May, 1543; 3 June, 1682; 1 July, 49; 5 Aug., 365; 2 Sept., 625; 23 Sept., 844

CHEMICALS, GENERAL

Allied Chemical Co., General Chemical Div.
1960: 22 Jan., 240; 18 Mar., 845; 22 July, 244

Eastern Chemical Corp.
1960: 7 Oct., 971

Harshaw Chemical Co.
1959: 13 Nov., 1346
1960: 8 Jan., 112; 29 Jan., 306

Mallinckrodt Chemical Works
1960: 18 Mar., 795; 20 May, 1473

Matheson Co., Inc., Matheson Coleman & Bell Div.
1960: 17 June, 1827; 22 July, 168

Pilot Chemicals, Inc.
1959: 23 Oct., 1146

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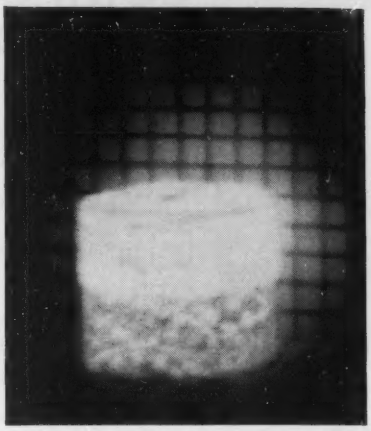

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Standard Scientific Supply Corp.
1960: 7 Oct., 966
Winthrop Laboratories
1959: 27 Nov., 1485
1960: 12 Feb., 425; 18 Mar., 843

CHEMICALS, ORGANIC

Allied Chemical Co.
1960: 18 Mar., 845
Eastern Chemical Corp.
1960: 7 Oct., 971
Matheson Co., Inc.
1960: 19 Aug., 484

CHEMICALS, TRACER

Baird-Atomic, Inc.
1960: 22 Apr., 1121; 20 May, 1515
New England Nuclear Corp.
1959: 9 Oct., 929; 23 Oct., 1129; 6 Nov., 1267; 20 Nov., 1432; 4 Dec., 1603; 18 Dec., 1717
1960: 1 Jan., 51; 15 Jan., 164; 29 Jan., 308; 12 Feb., 426; 26 Feb., 613; 11 Mar., 744; 25 Mar., 938; 8 Apr., 1053; 22 Apr., 1255; 6 May, 1385; 20 May, 1568; 3 June, 1684; 17 June, 1838; 1 July, 51; 15 July, 161; 29 July, 311; 12 Aug., 425; 26 Aug., 571; 9 Sept., 684; 23 Sept., 814; 7 Oct., 972
Nuclear-Chicago Corp.
1960: 29 Apr., 1332; 30 Sept., 908
Nuclear Corporation of America, Isotopes Specialties Co.
1960: 26 Aug., 577
Oak Ridge National Laboratory
1960: 19 Feb., 528; 18 Mar., 854; 22 Apr., 1224; 10 June, 1742; 23 Sept., 818
Picker X-Ray Corp.
1960: 20 May, 1489; 15 July, 107
Radiochemical Centre
1959: 13 Nov., 1347
1960: 8 Jan., 115; 5 Feb., 361; 29 Apr., 1325; 24 June, 1893; 22 July, 249; 16 Sept., 747
Schwarz BioResearch, Inc.
1959: 13 Nov., 1300; 18 Dec., 1715
1960: 18 Mar., 786; 15 Apr., 1107; 22 July, 172; 29 July, 307
Tracerlab, Inc.
1959: 23 Oct., 1141; 27 Nov., 1486
1960: 22 Apr., 1130

CHROMATOGRAPHY EQUIPMENT AND ACCESSORIES

American Instrument Co., Inc.
1959: 4 Dec., 1590
Atomic Accessories, Inc.
1959: 23 Oct., 1004
1960: 17 June, 1826
Barber-Colman Co., Wheelco Instruments Div.
1960: 22 Apr., 1156; 17 June, 1758; 22 July, 176; 26 Aug., 514
Beckman Instruments, Inc.
1959: 2 Oct., 825; 6 Nov., 1212; 20 Nov., 1379; 27 Nov., 1442
1960: 12 Feb., 374; 4 Mar., 629; 1 Apr., 956; 8 Apr., 1002; 10 June, 1694; 22 July, 166
California Laboratory Equipment Co.
1959: 23 Oct., 1116; 13 Nov., 1347; 4 Dec., 1601; 25 Dec., 1767
Central Scientific Co.
1960: 29 Jan., 308; 27 May, 1626; 7 Oct., 973
Corning Glass Works
1960: 22 Jan., 249

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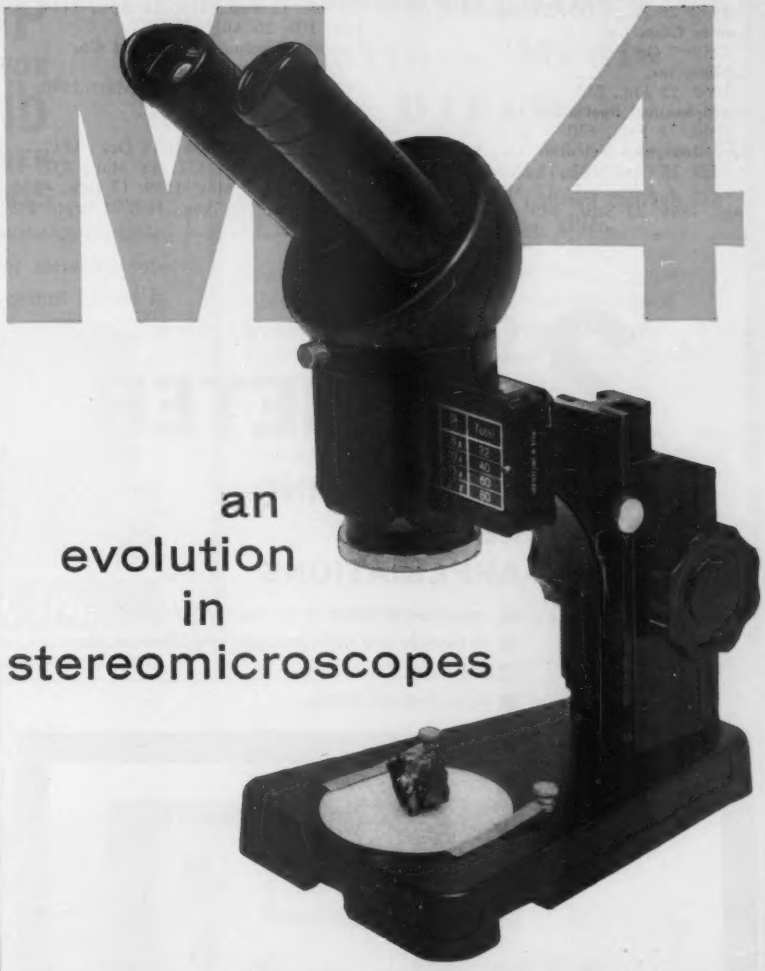

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F & M Scientific Corp.
1960: 18 Mar., 766; 20 May, 1486; 26 Aug., 562; 23 Sept., 769
Greiner, Emil, Co.
1960: 22 Jan., 249
Hamilton Co., Inc.
1960: 26 Aug., 513; 23 Sept., 831
Kontes Glass Co.
1959: 2 Oct., 826
Labline, Inc.
1960: 22 Jan., 233
Microchemical Specialties Co.
1960: 19 Feb., 530
New Brunswick Scientific Co., Inc.
1959: 23 Oct., 1123; 11 Dec., 1666
1960: 5 Feb., 367; 13 May, 1452; 24 June, 1896; 23 Sept., 849
Packard Instrument Co., Inc.
1959: 23 Oct., 1041; 11 Dec., 1628
1960: 22 Jan., 196; 19 Feb., 478; 1 Apr., 958; 27 May, 1582; 22 July, 190; 2 Sept., 590
Perkin-Elmer Corp., Instrument Div.
1960: 12 Feb., 376; 22 Apr., 1116; 15 July, 108; 26 Aug., 496
Phoenix Precision Instrument Co.
1959: 23 Oct., 1006
1960: 19 Feb., 550; 20 May, 1546; 23 Sept., 845
Photovolt Corp.
1959: 13 Nov., 1361; 18 Dec., 1717
1960: 19 Feb., 527; 18 Mar., 857; 22 Apr., 1231; 20 May, 1559; 17 June, 1825; 22 July, 245; 26 Aug., 563; 23 Sept., 839

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Reeve Angel
1960: 19 Feb., 454; 20 May, 1481
Research Specialties Co.
1959: 23 Oct., 1043
1960: 23 Sept., 816
Schaar and Co.
1960: 20 May, 1557
Schleicher, Carl, & Schuell Co.
1960: 16 Sept., 745
Schueler and Co., Schuco Scientific Div.
1960: 19 Feb., 565; 23 Sept., 814
Scientific Glass Apparatus Co., Inc.
1959: 23 Oct., 1026
Sigma Chemical Co.
1960: 26 Aug., 575
Technicon Chromatography Corp.
1960: 22 Apr., 1247; 17 June, 1837; 23 Sept., 853
Ultra-Violet Products, Inc.
1959: 13 Nov., 1364
Vanguard Instrument Co.
1959: 4 Dec., 1531
1960: 26 Aug., 506

CLAMPS

LaPine, Arthur S., and Co.
1960: 22 Jan., 250; 22 July, 246

CLASSROOM CHARTS

Welch, W. M., Manufacturing Co.
1959: 2 Oct., 867
1960: 1 Jan., 51; 3 June, 1685
Central Scientific Co.
1960: 22 Jan., 255; 18 Mar., 857; 13 May, 1452

CLEANSERS

Alconox, Inc.
1959: 6 Nov., 1269
1960: 22 Apr., 1245; 22 July, 240
Greiner, Emil, Co.
1960: 22 Apr., 1246; 17 June, 1820
Meinecke & Co., Inc.
1959: 23 Oct., 1114; 4 Dec., 1580
1960: 19 Feb., 474; 18 Mar., 868; 22 Apr., 1263; 17 June, 1834; 23 Sept., 828
Ultrasonic Industries, Inc.
1960: 22 Apr., 1238

COBALT-60 IRRADIATORS

Atomic Energy of Canada Limited
1960: 23 Sept., 781
Budd Co., Nuclear Systems Div.
1959: 9 Oct., 935

COLONY COUNTERS

American Optical Co.
1960: 3 June, 1692
New Brunswick Scientific Co., Inc.
1959: 23 Oct., 1123
1960: 8 Jan., 116; 26 Feb., 619; 3 June, 1687

COLORIMETERS AND ACCESSORIES

Bausch & Lomb Optical Co.
1959: 9 Oct., 896
1960: 1 Jan., 8; 9 Sept., 642
Beckman Instruments, Inc., Scientific and Process Instruments Div.
1960: 4 Mar., 628; 15 Apr., 1068; 29 July, 305
Fisher Scientific Co.
1960: 22 July, 174

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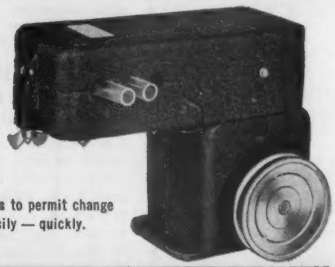

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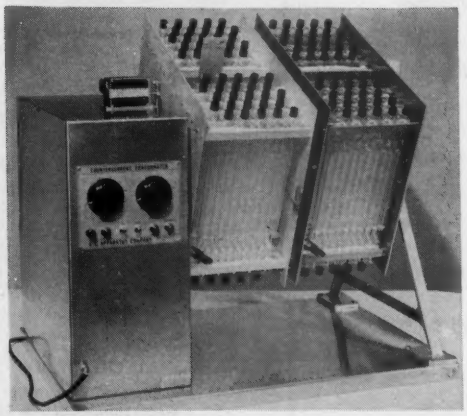

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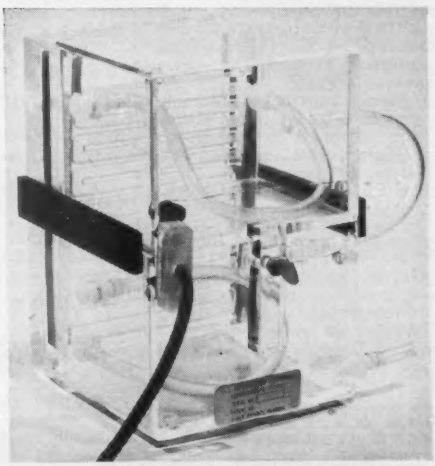

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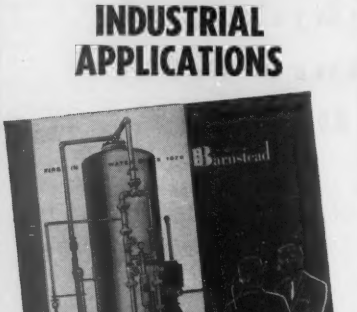

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1960: 22 Jan., 243; 5 Feb., 368; 19 Feb., 545; 4 Mar., 676; 18 Mar., 843; 1 Apr., 997; 15 Apr., 1106; 6 May, 1384; 27 May, 1626; 8 July, 94; 15 July, 159; 29 July, 311; 5 Aug., 369; 2 Sept., 628; 16 Sept., 747; 7 Oct., 973
Photovolt Corp.
1959: 9 Oct., 929; 11 Dec., 1663
1960: 8 Jan., 116; 22 Jan., 251; 11 Mar., 747; 8 Apr., 1055; 15 Apr., 1109; 27 May, 1628; 24 June, 1896; 1 July, 47; 15 July, 160; 19 Aug., 477
Thomas, Arthur H., Co.
1960: 8 Jan., 120

COMPUTERS

American Bosch Arma Corp.
1960: 10 June, 1698
Burroughs Corp., ElectroData Div.
1960: 18 Mar., 762, 763; 20 May, 1466, 1467
Donner Scientific Co.
1960: 18 Mar., 776
General Motors Research Laboratories
1960: 10 June, 1702
Royal McBee Corp.
1959: 2 Oct., 824; 6 Nov., 1216
1960: 25 Mar., 891; 29 July, 263

CONDUCTIVITY EQUIPMENT

Industrial Instruments, Inc.
1959: 13 Nov., 1365
1960: 22 Jan., 244; 18 Mar., 846; 22 Apr., 1232; 17 June, 1816; 26 Aug., 573

CONE, TAPER

Burdick & Jackson Laboratories
1960: 22 Apr., 1259

CONNECTORS, ELECTRICAL

Superior Electric Co.
1959: 13 Nov., 1349

CONTROLLERS

Smith, Arthur F., Inc.
1960: 7 Oct., 968

CRUCIBLES, PLATINUM-CLAD

Fisher Scientific Co.
1960: 20 May, 1571; 23 Sept., 777

CURRENT INTEGRATOR

Eldorado Electronics
1959: 23 Oct., 1150

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Harvard Apparatus Co., Inc.
1960: 18 Mar., 843

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1960: 22 Apr., 1248; 20 May, 1566

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Welch, W. M. Manufacturing Co.
1959: 23 Oct., 1113
1960: 4 Mar., 675; 7 Oct., 967

DESICCATORS

New York Laboratory Supply Co., Inc.
1960: 17 June, 1819
Precision Scientific Co.
1960: 19 Feb., 537; 22 Apr., 1244; 20 May, 1552

DISINTEGRATORS

Instrumentation Associates
1959: 23 Oct., 1152
1960: 20 May, 1554

DOSIMETERS

Bausch & Lomb Optical Co.
1960: 1 Jan., 8
Cambridge Instrument Co., Inc.
1960: 18 Mar., 844

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American Sterilizer Co.
1960: 22 July, 177; 23 Sept., 761
Blickman, S., Inc.
1960: 20 May, 1557
Greiner, Emil, Co.
1960: 19 Feb., 550
Kewaunee Scientific Equipment
1960: 19 Feb., 536

EGG PUNCH

Tri-R Instruments
1960: 22 Apr., 1258

ELECTROMAGNETS

Harvey-Wells Electronics, Inc.
1960: 18 Mar., 875; 22 Apr., 1225; 17 June, 1825; 22 July, 249

ELECTROMETERS

Applied Physics Corp.
1959: 6 Nov., 1266
1960: 22 Jan., 235; 22 July, 236
Nuclear-Chicago Corp.
1960: 1 Apr., 1000
Victoreen Instrument Co.
1960: 22 Jan., 252

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American Instrument Co., Inc.
1959: 4 Dec., 1512
Beckman Instruments, Inc., Spinco Div.
1959: 13 Nov., 1278; 11 Dec., 1614
1960: 8 Jan., 54; 22 Jan., 174; 11 Mar., 684; 22 Apr., 1114; 13 May, 1394; 17 June, 1776; 12 Aug., 374
Brinkman, C. A., & Co., Inc.
1959: 6 Nov., 1219

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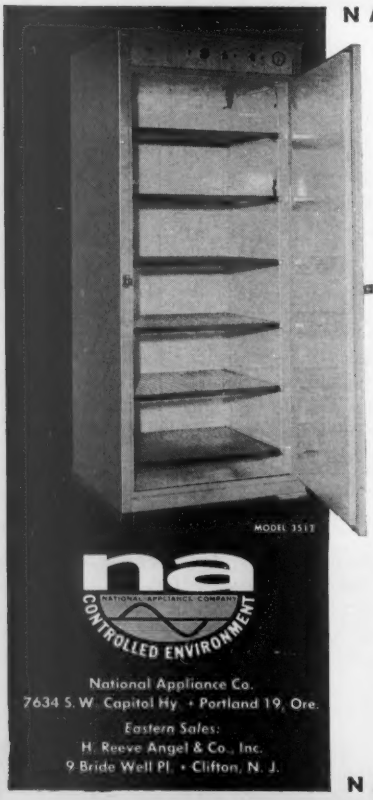
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1959: 23 Oct., 1126; 4 Dec., 1594
1960: 7 Oct., 964
Microchemical Specialties Co.
1960: 15 Jan., 169; 18 Mar., 851; 20 May, 1551; 17 June, 1841
National Instrument Laboratories, Inc.
1959: 23 Oct., 1032
1960: 18 Mar., 760
Perkin-Elmer Corp.
1959: 23 Oct., 1000
Photovolt Corp.
1959: 13 Nov., 1361; 20 Nov., 1431; 18 Dec., 1717
1960: 29 Jan., 307; 12 Feb., 425; 19 Feb., 527; 18 Mar., 857; 22 Apr., 1231; 20 May, 1559; 17 June, 1825; 22 July, 245; 26 Aug., 563; 23 Sept., 839
Schuler and Co., Schuco Scientific Div.
1960: 19 Feb., 565; 23 Sept., 814

EVAPORATORS

Buchler Instruments, Inc., formerly Laboratory Glass & Instrument Corp.
1959: 23 Oct., 1115
1960: 22 Jan., 180; 19 Feb., 460; 22 Apr., 1244; 20 May, 1565
Instrumentation Associates
1960: 18 Mar., 846

EXTRACTORS

VirTis Co., Inc.
1960: 22 July, 180

FERMENTOR DRIVE ASSEMBLY

New Brunswick Scientific Co., Inc.
1959: 2 Oct., 873; 6 Nov., 1268
1960: 15 Jan., 165; 25 Mar., 943

FILM, INTERFERENCE

Fish-Schurman Corp.
1960: 20 May, 1542

FILM, BADGES

Nuclear Corporation of America, Isotopes Specialties Co.
1960: 26 Aug., 577

FILTERS

Custom Scientific Instruments, Inc.
1960: 22 Jan., 234; 22 July, 236; 23 Sept., 834
Millipore Filter Corp.
1959: 23 Oct., 1140; 13 Nov., 1362; 20 Nov., 1430; 4 Dec., 1602
1960: 22 Apr., 1257
Reeve Angel
1960: 23 Sept., 768
Schleicher, Carl, & Schuell. Co.
1960: 22 Apr., 1264

FILTERS, INTERFERENCE

Baird-Atomic, Inc.
1959: 4 Dec., 1603
1960: 19 Feb., 531; 18 Mar., 792; 23 Sept., 765
Bausch & Lomb Optical Co.
1960: 12 Feb., 384
Fish-Schurman Corp.
1959: 23 Oct., 1141

1960: 19 Feb., 545; 22 Apr., 1236; 20 May, 1542

Photovolt Corp.
1959: 30 Oct., 1203; 4 Dec., 1589
1960: 1 Apr., 993; 8 July, 97; 2 Sept., 627

FILTER PAPER

New York Laboratory Supply Co., Inc.
1959: 20 Nov., 1431
1960: 18 Mar., 863

Reeve Angel
1960: 19 Feb., 454; 20 May, 1481

Schleicher, Carl, & Schuell Co.
1959: 23 Oct., 1133; 13 Nov., 1357; 4 Dec., 1598
1960: 22 Apr., 1264; 13 May, 1402; 17 June, 1816

FLASKS

Bellco Glass, Inc.
1959: 4 Dec., 1507; 18 Dec., 1713
1960: 8 Jan., 113; 22 Jan., 255; 5 Feb., 368; 19 Feb., 539; 3 June, 1689; 17 June, 1842; 8 July, 94; 9 Sept., 684; 7 Oct., 970

Corning Glass Works
1960: 11 Mar., 745; 8 Apr., 1011; 8 July, 100

Doerr Glass Co.
1959: 13 Nov., 1283

F & M Scientific Corp.
1960: 18 Mar., 766; 20 May, 1486; 23 Sept., 827

Falcon Plastics Co.
1960: 1 July, 5

Kimble Glass Co.
1960: 15 Jan., 123; 22 Jan., 183; 11 Mar., 689

Kontes Glass Co.
1959: 23 Oct., 1120
1960: 22 Jan., 253; 19 Feb., 558; 18 Mar., 859; 22 Apr., 1228

FLOWMETERS, GAS

Matheson Co., Inc.
1959: 23 Oct., 1125

FLUOROMETERS

Coleman Instruments, Inc.
1959: 23 Oct., 1047

Farrand Optical Co., Inc.
1959: 23 Oct., 1116; 13 Nov., 1361; 4 Dec., 1607
1960: 18 Mar., 844; 22 Apr., 1251; 22 July, 235; 26 Aug., 571; 23 Sept., 821

Klett Manufacturing Co.
1959: 9 Oct., 931; 23 Oct., 1132; 20 Nov., 1432; 18 Dec., 1717; 25 Dec., 1767
1960: 1 Jan., 47; 29 Jan., 305; 11 Mar., 747; 25 Mar., 945; 22 Apr., 1236; 10 June, 1746; 17 June, 1833; 26 Aug., 575; 9 Sept., 686

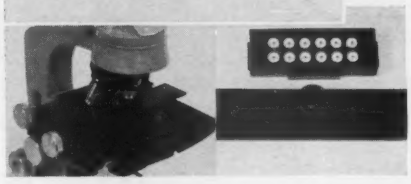
Perkin-Elmer Corp., Instrument Div.
1960: 15 Jan., 124

Photovolt Corp.
1959: 6 Nov., 1271
1960: 15 Jan., 165; 26 Feb., 613; 11 Mar., 747; 15 Apr., 1109; 13 May, 1457; 27 May, 1628; 24 June, 1896; 1 July, 47; 19 Aug., 477; 16 Sept., 749

Thomas, Arthur H., Co.
1960: 18 Mar., 888; 22 July, 260; 16 Sept., 752

Will Corp.
1960: 19 Feb., 561

CANALCO ANALYZERS TAKE THE LABOR OUT OF LABORATORY



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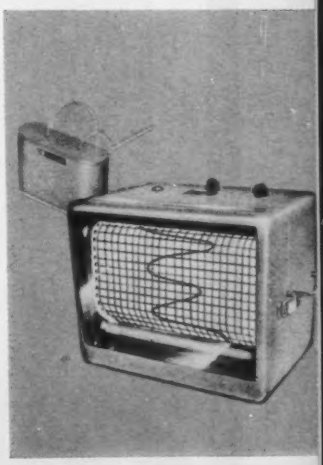

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FRACTIONATORS

E-C Apparatus Co.
1959: 2 Oct., 869; 4 Dec., 1605
Gilson Medical Electronics
1959: 13 Nov., 1367
1960: 18 Mar., 849

FRACTION COLLECTORS AND ACCESSORIES

Buchler Instruments, Inc., formerly Laboratory Glass & Instrument Corp.
1960: 22 Jan., 180; 19 Feb. 460; 22 Apr., 1221; 9 Sept., 684
Gilson Medical Electronics
1959: 13 Nov., 1367
1960: 12 Feb., 427; 18 Mar., 849
Hamilton Co., Inc.
1959: 13 Nov., 1358
1960: 19 Feb., 544; 24 June, 1897
Microchemical Specialties Co.
1959: 4 Dec., 1608
National Instrument Laboratories, Inc.
1960: 22 Jan., 251; 22 Apr., 1255
Packard Instrument Co., Inc.
1960: 1 Apr., 958; 27 May, 1582; 22 July, 190; 2 Sept., 590
Schaar and Co.
1960: 20 May, 1557

FREEZE-DRYING EQUIPMENT

American Hospital Supply Corp., Scientific Products Div.
1959: 4 Dec., 1521

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American Sterilizer Co.
1960: 22 July, 177; 26 Aug., 509; 23 Sept., 761
Buchler Instruments, Inc., formerly Laboratory Glass & Instrument Corp.
1960: 18 Mar., 875; 22 Apr., 1231
Repp Industries, Inc.
1960: 19 Feb., 446; 22 Apr., 1122; 26 Aug., 501
Scientific Glass Apparatus Co., Inc.
1960: 25 Mar., 942
VirTis Co., Inc.
1959: 23 Oct., 1038
1960: 22 Jan., 184; 18 Mar., 771; 23 Sept., 762

FUME HOODS

Aloe, A. S., Co., Aloe Scientific Div.
1960: 18 Mar., 879
Blickman, S., Inc.
1960: 20 May, 1557

FUNNELS

Nalge Co., Inc.
1960: 1 Apr., 995
VirTis Co., Inc.
1960: 22 July, 180
Will Corp.
1960: 22 Apr., 1267; 27 May, 1625

FURNACES

Hevi-Duty Electric Co.
1959: 23 Oct., 1124; 4 Dec., 1592
1960: 19 Feb., 542; 15 July, 156
Lindberg Engineering Co.
1960: 22 Apr., 1236; 20 May, 1565
New York Laboratory Supply Co., Inc.
1959: 20 Nov., 1431
Thermo Electric Manufacturing Co.
1959: 23 Oct., 1121; 4 Dec., 1585

FURNITURE, LABORATORY

Ajusto Equipment Co.
1960: 23 Sept., 846
Aloe, A. S., Co., Aloe Scientific Div.
1960: 18 Mar., 879
Blickman, S., Inc.
1960: 23 Sept., 830
Brinkmann Instruments, Inc.
1959: 27 Nov., 1486; 25 Dec., 1767
Brunswick-Balke-Collender Co.
1960: 17 June, 1835
Central Scientific Co.
1960: 12 Aug., 425
Duralab Equipment Corp.
1960: 18 Mar., 881; 17 June, 1827; 23 Sept., 840
Fisher Scientific Co.
1959: 16 Oct., 992
1960: 22 Jan., 189
Graphic Systems
1959: 13 Nov., 1354
1960: 22 Jan., 242; 18 Mar., 870; 20 May, 1554; 22 July, 242; 23 Sept., 845
Harshaw Chemical Co.
1959: 23 Oct., 1112; 13 Nov., 1346
1960: 8 Jan., 112; 29 Jan., 306
Johns-Manville
1959: 9 Oct., 887; 6 Nov., 1215; 4 Dec., 1523
Kewaunee Scientific Equipment
1960: 19 Feb., 536
LABASCO
1960: 17 June, 1818; 23 Sept., 820
Laboratory Construction Co.
1960: 23 Sept., 814

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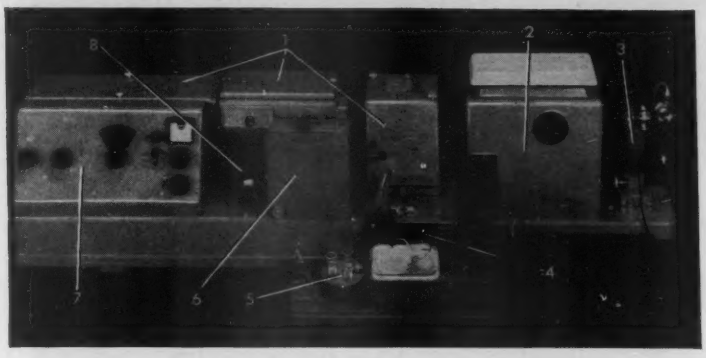

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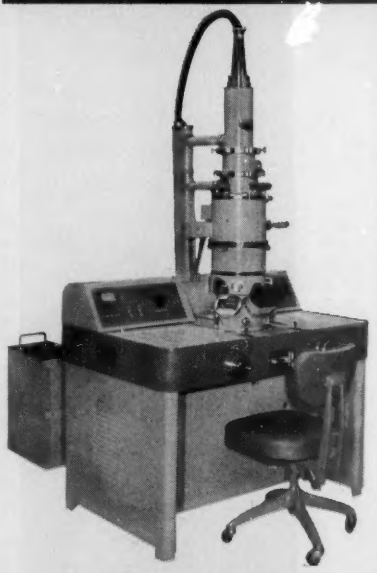

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Lab-Tek Plastics Co.
1959: 23 Oct., 1122; 4 Dec., 1582
Metalab Equipment Co.
1960: 19 Feb., 547
Will Corp.
1960: 20 May, 1516, 1517

GALVANOMETERS

Cambridge Instrument Co., Inc.
1960: 23 Sept., 830
Photovolt Corp.
1959: 27 Nov., 1486; 25 Dec., 1767
1960: 22 Jan., 251; 8 Apr., 1055; 13 May, 1457; 15 July, 160
Texas Instruments, Inc.
1960: 18 Mar., 887

GAMMA IRRADIATORS

Atomic Energy of Canada Limited
1959: 23 Oct., 1008; 4 Dec., 1520
1960: 22 Jan., 178; 18 Mar., 782; 22 Apr., 1150; 20 May, 1488
Budd Co.
1960: 9 Oct., 935
Curtiss-Wright Corp., Princeton Div.
1959: 23 Oct., 1143
Victoreen Instrument Co.
1959: 23 Oct., 1131
1960: 22 Jan., 252; 19 Feb., 557; 29 Apr., 1284; 20 May, 1490

GAS CONTAINERS

Union Carbide Corp., Linde Co. Div.
1959: 18 Dec., 1718
1960: 22 Apr., 1262; 12 Aug., 426; 7 Oct., 962

GAS FLOW CONTROL DEVICES

Granville-Phillips Co.
1960: 7 Oct., 970

GAS METERS

Thomas, Arthur H., Co.
1959: 2 Oct., 876

GAUGES, VACUUM

Ace Glass, Inc.
1960: 22 July, 237
Central Scientific Co.
1959: 27 Nov., 1485
Greiner, Emil, Co.
1960: 23 Sept. 853
New York Air Brake Co., Kinney Vacuum Div.
1960: 19 Feb., 533; 18 Mar., 849; 22 Apr., 1225; 17 June, 1819; 19 Aug., 483
Smith, Arthur F., Inc.
1960: 17 June, 1844; 7 Oct., 968

GAUSSMETERS

Harvey-Wells Electronics, Inc.
1960: 17 June, 1825

GLASS, PLASTIC COATED

Ace Glass, Inc.
1960: 19 Feb., 529

GLASS CUTTERS

Standard Scientific Supply Corp.
1960: 18 Mar., 862

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East Rutherford, New Jersey

Welch, W. M., Manufacturing Co.
1960: 1 Apr., 993; 2 Sept., 627

GLASSBLOWING KIT

Bethlehem Apparatus Co., Inc.
1960: 17 June, 1832; 22 July, 234; 26 Aug., 560

GLASSWARE AND ACCESSORIES

Ace Glass, Inc.
1960: 22 Jan., 247; 19 Feb., 529; 18 Mar., 855; 20 May, 1547
Bellco Glass, Inc.
1959: 4 Dec., 1507; 18 Dec., 1713
1960: 8 Jan., 113; 22 Jan., 255; 22 Apr., 1243; 6 May, 1385; 8 July, 94; 5 Aug., 367; 19 Aug., 482; 9 Sept., 684; 23 Sept., 850; 7 Oct., 970
Corning Glass Works
1959: 9 Oct., 891; 6 Nov., 1265; 13 Nov., 1349; 4 Dec., 1527
1960: 5 Feb., 322, 323; 11 Mar., 745; 3 June, 1636; 8 July, 100; 5 Aug., 320; 9 Sept., 687
Doerr Glass Co.
1959: 9 Oct., 883; 13 Nov., 1283; 4 Dec., 1499
1960: 26 Feb., 573; 18 Mar., 759; 15 Apr., 1067; 13 May, 1403; 16 Sept., 700
Fischer & Porter Co.
1959: 13 Nov., 1287
1960: 22 Jan., 194; 19 Feb., 457
Harshaw Chemical Co.
1959: 23 Oct., 1112; 13 Nov., 1346
1960: 8 Jan., 112; 29 Jan., 306
Kimble Glass Co.
1959: 2 Oct., 823; 30 Oct., 1164; 6 Nov., 1222; 20 Nov., 1375; 4 Dec., 1519; 18 Dec., 1675
1960: 15 Jan., 123; 22 Jan., 183; 11 Mar., 689; 15 Apr., 1072; 10 June, 1701; 8 July, 58; 9 Sept., 639
Klett Manufacturing Co.
1959: 2 Oct., 867; 16 Oct., 988; 23 Oct., 1132; 6 Nov., 1269; 13 Nov., 1347; 20 Nov., 1432; 27 Nov., 1486; 4 Dec., 1597; 11 Dec., 1665; 18 Dec., 1717
1960: 1 Jan., 47; 8 Jan., 115; 15 Jan., 165; 22 Jan., 243; 29 Jan., 305; 5 Feb., 368; 12 Feb., 425; 4 Mar., 676; 11 Mar., 747; 1 Apr., 997; 8 Apr., 1051; 15 Apr., 1106; 22 Apr., 1236; 29 Apr., 1325; 13 May, 1452; 20 May, 1552; 27 May, 1626; 3 June, 1687; 10 June, 1746; 17 June, 1833; 24 June, 1896; 1 July, 47; 15 July, 159; 22 July, 254; 29 July, 311; 12 Aug., 429; 19 Aug., 477; 26 Aug., 575; 2 Sept., 628; 9 Sept., 686; 16 Sept., 747; 23 Sept., 850; 30 Sept., 905
Kontes Glass Co.
1959: 2 Oct., 826; 16 Oct., 985; 23 Oct., 1120; 30 Oct., 1204; 6 Nov., 1220; 13 Nov., 1366; 4 Dec., 1588
1960: 22 Jan., 253; 19 Feb., 558; 22 Apr., 1228
Microchemical Specialties Co.
1960: 22 Apr., 1222
Scientific Glass Apparatus Co., Inc.
1959: 23 Oct., 1026
1960: 19 Feb., 466
Thomas, Arthur H., Co.
1960: 15 Apr., 1112

GLOVES, DRY BOX

Charleston Rubber Co.
1960: 19 Feb., 534

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GLOVES, POLYETHYLENE

Research Associates, Inc.
1960: 20 May, 1568

GONIOMETERS

LaPine, Arthur S., and Co.
1690: 22 Apr., 1229

GROWTH CHAMBERS

American Sterilizer Co.
1960: 22 July, 177; 23 Sept., 761
Delmar Scientific Laboratories
1959: 23 Oct., 1028
Labline, Inc.
1960: 20 May, 1545
National Appliance Co.
1960: 20 May, 1539

GYROSCOPES

Central Scientific Co.
1959: 30 Oct., 1203; 4 Dec., 1581

HAND TORCHES

Bethlehem Apparatus Co., Inc.
1960: 20 May, 1556

HEATERS

Research Specialties Co.
1959: 16 Oct., 986

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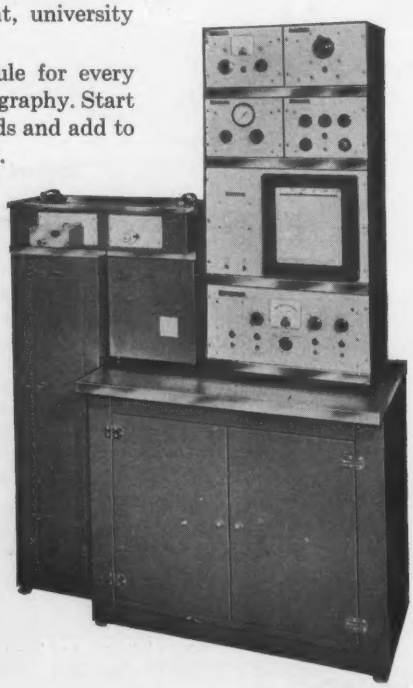

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Scientific Glass Apparatus Co., Inc.
1960: 25 Mar., 942
Thermo Electric Manufacturing Co.
1959: 23 Oct., 1121

HEATING TAPES

Standard Scientific Supply Corp.
1960: 22 July, 256

HOMOGENIZERS

Instrumentation Associates
1960: 22 Apr., 1248
Sorvall, Ivan, Inc.
1960: 20 May, 1561; 22 July, 231; 26 Aug., 567
Tri-R Instruments
1959: 23 Oct., 1137
1960: 19 Feb., 555
VirTis Co., Inc.
1959: 23 Oct., 1038
1960: 20 May, 1476; 17 June, 1773

HOT PLATES

Central Scientific Co.
1960: 26 Feb., 619; 17 June, 1838
Lindberg Engineering Co., Laboratory Equipment Div.
1960: 22 Jan., 237
Precision Scientific Co.
1960: 19 Feb., 527
Thermo Electric Manufacturing Co.
1959: 23 Oct., 1121

ILLUMINATORS

American Optical Co.
1960: 26 Feb., 622; 23 Sept., 856
Bausch & Lomb Optical Co.
1960: 26 Feb., 578
Burton Manufacturing Co.
1959: 23 Oct., 1152
1960: 19 Feb., 552; 22 Apr., 1224
Hacker, William J., & Co., Inc.
1960: 22 Apr., 1126

INCINERATORS

Phipps & Bird, Inc.
1960: 26 Aug., 575

INCUBATORS

National Appliance Co.
1959: 23 Oct., 1118
1960: 5 Feb., 362; 6 May, 1388; 26 Aug., 556; 23 Sept., 847
Precision Scientific Co.
1959: 4 Dec., 1588
1960: 18 Mar., 846; 20 May, 1540; 26 Aug., 568

INFUSION APPARATUS

Will Corp., Bronwill Scientific Div.
1960: 10 June, 1749; 23 Sept., 849

INJECTORS

Foringer & Co., Inc.
1960: 7 Oct., 971

INTERFEROMETERS

Central Scientific Co.
1959: 11 Dec., 1666
1960: 15 Jan., 164; 17 June, 1833

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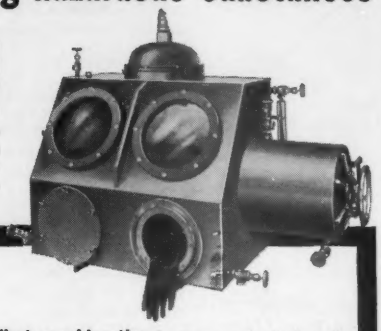

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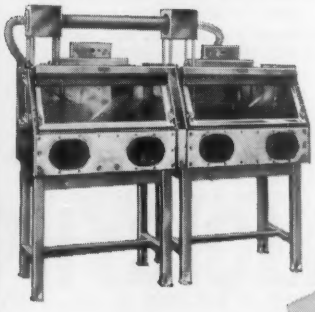

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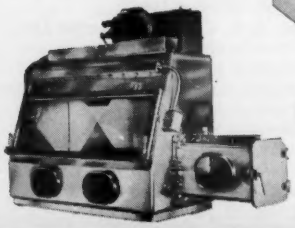

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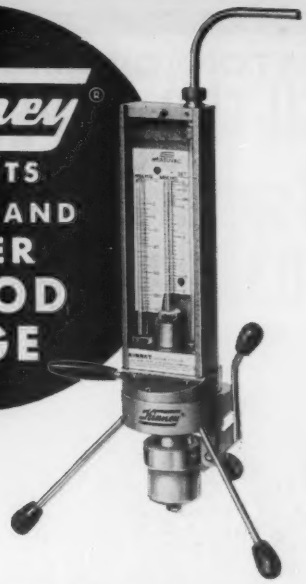
Kinney® PRESENTS A NEW AND BETTER McLEOD GAGE



READS EASIER

•

USES LESS MERCURY

•

PANEL OR PORTABLE MOUNT

•

SEPARATE CAPILLARIES

•

2 SCALES
150 mm to 2 mm
2,000μ to 1μ

•

ACCURATE LIGHT IN WEIGHT COMPACT

The KINNEY McLeod Gage answers the many objections to other gages now in use. Its advanced design compacts superior performance into a rugged, versatile instrument that may be permanently mounted on bracket, tank, panel or pipe or, by affixing demountable legs, used as a portable unit.

The KINNEY McLeod Gage covers a broad range of pressures . . . accurate readings from 150 mm Hg to 1 Micron Hg. This exceptional range of pressure readings is achieved by incorporating two separate capillaries having separate compression ratios, making available measurements of 150 mm to 2 mm and 2,000 microns to 1 micron. Unlike other McLeod Gages, the reading capillary tubes are completely separate and replaceable—easily detached from the main body at the knurled sealing glands. Because these tubes are reproducible, complete accuracy between each gage is assured.

The KINNEY McLeod Gage requires less mercury and it is supremely simple to add mercury, remove it for cleaning or recharge the gage. Operation requires no special skill . . . readings are achieved quickly, easily and confidently. Write for full information and prices today.

Get all the facts on the NEW KINNEY McLEOD GAGE. Write today!

KINNEY VACUUM DIVISION
THE NEW YORK AIR BRAKE COMPANY
3538K WASHINGTON STREET • BOSTON 30 • MASS.

Please send me Bulletin No. 3821.1 and prices on the KINNEY McLeod Gage.

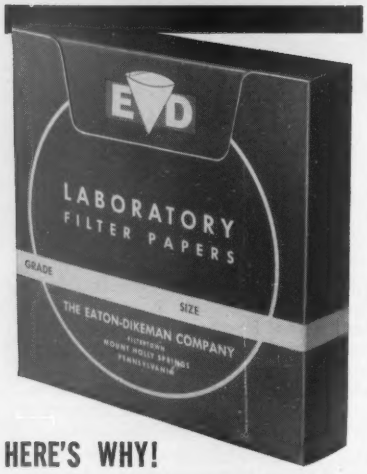
Name_____

Company_____

Address_____

City_____ State_____

EATON-DIKEMAN
FILTER PAPER
Used in 7 out of 10 laboratories



HERE'S WHY!

• Complete range — whatever rapidity, and retention characteristics you desire, chances are there's a standard E-D paper available. Made with smooth or creped surfaces, in plain or fluted circles, in strips, or rolls, or cut to your individual requirements.

• Highest purity — only the purest pulp available is used.

• Uniform quality — every step of the manufacturing process is carefully controlled and checked.

• Excellent wet strength — special resins incorporated.

• Complete technical service — whatever your filtering problem may be, Eaton-Dikeman with its broad background of more than seventy years of manufacturing filter papers exclusively, can probably solve it.

Also available—papers for chromatography and electrophoresis, as well as bibulous and lens papers. Write for free samples.

E D

EATON-DIKEMAN CO.
Mount Holly Springs, Pennsylvania

KYMOGRAPHS AND ACCESSORIES

Phipps & Bird, Inc.
1959: 23 Oct., 1109; 13 Nov., 1367; 4 Dec., 1607
1960: 4 Mar., 675; 11 Mar., 743; 25 Mar., 943; 1 Apr., 997; 8 Apr., 1051; 10 June, 1743; 17 June, 1842; 24 June, 1893; 1 July, 51; 8 July, 94; 15 July, 161; 7 Oct., 967

LABELS, TIME

Professional Tape Co., Inc.
1960: 4 Mar., 675; 11 Mar., 744; 18 Mar., 873; 25 Mar., 938; 1 Apr., 993; 29 Apr., 1327; 6 May, 1386; 27 May, 1626; 3 June, 1684; 24 June, 1893; 2 Sept., 628; 23 Sept., 846; 7 Oct., 972

LABELS, MICROSCOPIC SLIDE

Professional Tape Co., Inc.
1959: 16 Oct., 987; 23 Oct., 1113; 13 Nov., 1368; 20 Nov., 1437; 4 Dec., 1583; 11 Dec., 1663
1960: 8 Jan., 113; 22 Jan., 243; 5 Feb., 365; 19 Feb., 549; 11 Mar., 743; 25 Mar., 941; 15 Apr., 1106; 20 May, 1537; 17 June, 1823; 16 Sept., 749

LABORATORY EQUIPMENT

Analytical Equipment, Inc.
1959: 23 Oct., 1144
Fisher Scientific Co.
1959: 23 Oct., 1020
1960: 20 May, 1571; 23 Sept., 777
Standard Scientific Supply Corp.
1960: 7 Oct., 966
Will Corp.
1959: 23 Oct., 1127
1960: 20 May, 1516, 1517

LABORATORY EQUIPMENT, PLASTIC

Bel-Art Products
1960: 19 Feb., 555
Burdick & Jackson Laboratories
1960: 22 Apr., 1259
Falcon Plastics Co.
1959: 23 Oct., 1035
1960: 19 Feb., 534; 24 June, 1860; 1 July, 5
Nalge Co., Inc.
1960: 19 Feb., 532; 18 Mar., 872; 22 Apr., 1227; 20 May, 1564; 1 Apr., 995; 17 June, 1824; 22 July, 248; 26 Aug., 570; 23 Sept., 824
Thomas, Arthur H., Co.
1959: 18 Dec., 1714

LABORATORY JACK

Central Scientific Co.
1959: 23 Oct., 1144; 18 Dec., 1713

LAMPS

Aristo Grid Lamp Products, Inc.
1960: 22 Apr., 1252
Ultra-Violet Products, Inc.
1959: 23 Oct., 1151; 4 Dec., 1592

MACHINE TOOLS

American-Edelstaal Unimat Division
1959: 23 Oct., 1118; 13 Nov., 1365; 4 Dec., 1593; 11 Dec., 1667
1960: 22 Jan., 244; 19 Feb., 542; 18 Mar., 874; 17 June, 1840; 22 July, 246; 26 Aug., 562

MACROSCOPES

Bausch & Lomb Optical Co.
1959: 23 Oct., 1050; 4 Dec., 1534
1960: 29 Jan., 268; 1 July, 8
Ednalite Optical Co., Inc.
1959: 4 Dec., 1504

MANIKIN, RADIATION-EQUIVALENT

Atomic Accessories, Inc.
1959: 23 Oct., 1004

MANOMETERS

Ace Glass, Inc.
1960: 22 July, 237
Greiner, Emil, Co.
1960: 20 May, 1556
Phipps & Bird, Inc.
1959: 23 Oct., 1109

MATERIALS TESTING EQUIPMENT

Instron Engineering Corp.
1960: 18 Mar., 839; 22 Apr., 1140; 24 June, 1899

MEASURING EQUIPMENT, PHYSIOLOGICAL

American Hospital Supply Corp.
1960: 18 Mar., 761
Beckman Instruments, Inc., Spinco Div.
1960: 8 July, 54; 9 Sept., 634
Biophysical Electronics
1960: 19 Feb., 556; 22 Apr., 1252; 20 May, 1562
Precision Instrument Co.
1960: 17 June, 1822; 22 July, 255
Riseman Development Laboratory
1960: 26 Aug., 572; 23 Sept., 850

MELTING POINT APPARATUS

LaPine, Arthur S., and Co.
1960: 19 Feb., 560; 22 Apr., 1229; 17 June, 1840
Standard Scientific Supply Corp.
1960: 23 Sept., 842
Thomas, Arthur H., Co.
1959: 23 Oct., 998

MICROANALYSIS EQUIPMENT

Ace Glass, Inc.
1960: 20 May, 1547
Aloe, A. S., Co., Aloe Scientific Div.
1959: 4 Dec., 1600
1960: 5 Feb., 365
Beckman Instruments, Inc., Spinco Div.
1960: 8 July, 54; 9 Sept., 634
Brinkmann Instruments, Inc.
1959: 13 Nov., 1359
1960: 23 Sept., 770
Brunswick Corp., Aloe Scientific Div.
1960: 22 July, 243
Corning Glass Works
1959: 13 Nov., 1349
Hamilton Co., Inc.
1960: 22 Apr., 1234; 22 July, 253
Harvard Apparatus Co., Inc.
1959: 13 Nov., 1368
Kontes Glass Co.
1959: 2 Oct., 826; 4 Dec., 1588

PHOTOVOLT
Electronic pH METERS

A complete line of pH meters, incorporating permanently frictionless taut-suspension indicating meters, modern electronic tubes and circuits. Simple in operation and maintenance; featuring sealed amplifier plug-in units.

Two-way pH Meter Model 85

- Single range 0-14, scale length 3", readable to 0.05 pH Unit.
- Available — compact battery pack for field use ($38.00 addtl.).
- Fully stabilized, simple, usable with all types of electrodes.

Write for Bulletin #195

$135

High Precision pH Meter Model 110

- Single range 0-14, scale length 7", readable to 0.02 pH unit.
- Temperature control 0-100° C., voltage selector for 80-260 volts.
- Available — carrying cover and baseboard for bottles, beakers.

Write for Bulletin #105

$235

Standard Laboratory pH Meter Model 115

- Single range 0-14, scale length 4", readable to 0.05 pH unit.
- Temperature control 20-100° C., available with carrying case.
- Additional millivolt scale for redox measurements and titrations.

Write for Bulletin #225

$175

Portable pH Meter Model 125

- Single range 0-14, scale length 5½", readable to 0.03 pH unit.
- Only 3 batteries, standard radio type, 2,000 hours of service.
- Available — carrying frame for instrument, beakers, bottles.

Write for Bulletin #118

$195

Tester Model 25 for Checking and Adjusting pH Meters

A compact, inexpensive instrument without batteries; for checking performance of PHOTOVOLT and other pH meters. Requires neither electrodes nor buffers. Write for Bulletin #138 **$68**

PHOTOVOLT CORPORATION
95 Madison Avenue, New York 16, N.Y.

PUMPS FOR PHYSIOLOGICAL RESEARCH

Many phases of physiological research require apparatus which will effect the uniform and predictable flow of liquids and gasses. To meet such situations, Harvard Apparatus Co., Inc., makes available, at the lowest possible cost, an extremely wide range of pumping equipment.

In addition to providing the standard pumps described below, Harvard Apparatus Co., Inc., can also manufacture to order special apparatus needed in unusual situations. Inquiries are invited.

All pumps are made with the same fine workmanship and materials that have characterized the Company's equipment for so many years. Each pump will perform exactly as specified and will give years of trouble-free service.

INFUSION-WITHDRAWAL PUMPS

All pumps in this group are operated by synchronous reversing motors and achieve the transfer of liquids by means of motor-driven mechanisms acting on standard Luer-Lok syringes. The syringe piston is attached to a weighted half-nut which rests on a precision-cut lead screw. As the screw turns, a very uniform intake or discharge of liquid takes place. Pre-set limit stops automatically stop pumping action.

Single, dual and multiple syringe models are available, ranging from simple types designed for either infusion or withdrawal to those performing both operations continuously and automatically over extended periods of time.

Both single and multi-speed models are available. The multi-speed pumps are equipped with a transmission which provides 12 separate speeds and 72 pumping rates using syringes from 50 to 2 cc. size. Single speed units deliver one fixed speed and 6 pumping rates using syringes in the same range of sizes. A range of motors from 1 to 1800 R.P.M. is available.

RESPIRATION PUMPS

These are motor-operated, positive displacement pumps for use with small mammals. Air or gas is drawn into a cylinder in one half of the cycle and delivered to the animal in the next half of the cycle. The stroke volume is adjustable mechanically from 30 to 750 cc. per stroke. A motor-operated slide valve provides separate ports for inspiration and expiration. The expired air may be collected or recycled at the slide valve.

Single and multi-speed models are available. In the latter, motor and speed control box produce rates continuously adjustable from 7 to 50 strokes per minute. The single speed model produces a fixed rate of 22 strokes per minute.

PERISTALTIC PUMPS

These are heavy-duty units achieving the continuous flow of liquids by means of peristaltic action on the outside of rubber tubing.

Catalog 1960-61 and Data Sheets are available on request.

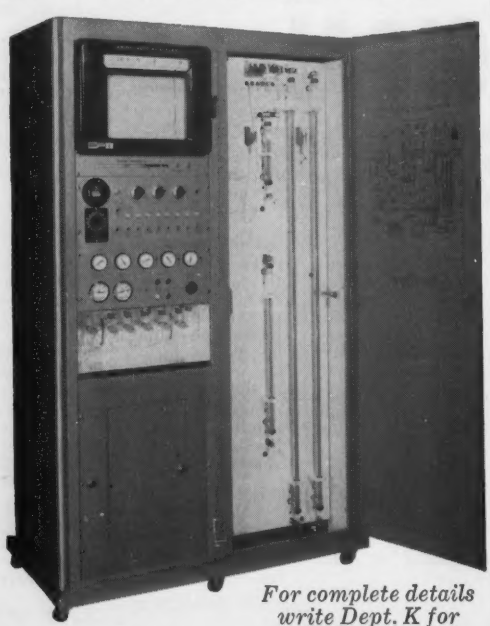
HARVARD APPARATUS CO., INC. • Dover, Mass., U.S.A.

(a non-profit organization)

NEW PHOENIX MODEL K-5000-A
AMINO ACID ANALYZER

Now Available For Combined Analytical— Preparative Analysis With the

MODEL 5500 STREAM SPLITTING SYSTEM



For complete details write Dept. K for Bulletin K 5000-A

PPI

PHOENIX PRECISION INSTRUMENT COMPANY

3803-05 NORTH FIFTH ST., PHILADELPHIA 40, PENNSYLVANIA

Macalaster Bicknell Co.
1960: 22 Apr., 1261
Microtech Services Co.
1959: 2 Oct., 872
Phipps & Bird, Inc.
1960: 26 Aug., 575
Sauter, August, of New York, Inc.
1960: 26 Aug., 554
Stoelting, C. H., Co.
1960: 20 May, 1568; 23 Sept., 833
VirTis Co., Inc.
1960: 22 July, 180
Will Corp., Bronwill Scientific Div.
1960: 4 Mar., 676; 15 Apr., 1108; 20 May, 1557; 17 June, 1838; 19 Aug., 489

MICROBIOLOGICAL MEDIA

Colorado Serum Co.
1959: 23 Oct., 1132; 13 Nov., 1363; 4 Dec., 1597
1960: 15 Jan., 165; 19 Feb., 537; 18 Mar., 857; 22 Apr., 1226; 9 Sept., 681
Difco Laboratories
1959: 23 Oct., 1113; 13 Nov., 1351; 18 Dec., 1713
1960: 22 Jan., 255; 19 Feb., 527; 18 Mar., 853; 22 Apr., 1221; 20 May, 1537; 17 June, 1833; 22 July, 239; 26 Aug., 563; 23 Sept., 833
Hyland Laboratories
1960: 22 Jan., 236; 19 Feb., 562; 18 Mar., 876; 22 Apr., 1243; 20 May, 1559; 17 June, 1815; 22 July, 232; 26 Aug., 559; 23 Sept., 817

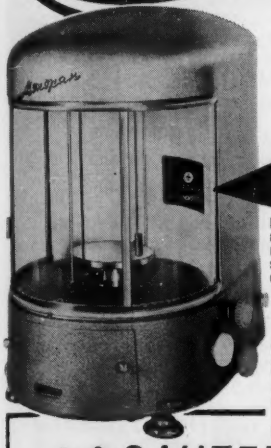
MICROMANIPULATORS

Aloe, A. S., Co., Aloe Scientific Div.
1959: 4 Dec., 1600
1960: 5 Feb., 365
Brinkmann Instruments, Inc.
1959: 13 Nov., 1359
Brunswick Corp., Aloe Scientific Div.
1960: 22 July, 243
Stoelting, C. H., Co.
1960: 20 May, 1568; 23 Sept., 833

MICROSCOPES

American Optical Co.
1959: 20 Nov., 1440
1960: 29 Jan., 312; 11 Mar., 750; 12 Feb., 432; 17 June, 1848; 26 Aug., 580; 7 Oct., 976
Bausch & Lomb Optical Co.
1959: 18 Dec., 1680
1960: 15 July, 114; 26 Aug., 518
Cooke, Troughton & Simms
1960: 18 Mar., 768; 8 Apr., 1012; 29 Apr., 1276; 20 May, 1469; 12 Aug., 384; 9 Sept., 686; 23 Sept., 767; 7 Oct., 972
Elgeet Optical Co., Inc., Scientific Instrument and Apparatus Div.
1959: 23 Oct., 1016; 4 Dec., 1514
1960: 19 Feb., 465; 22 Apr., 1120; 10 June, 1699; 22 July, 185; 5 Aug., 318; 19 Aug., 491; 2 Sept., 631; 16 Sept., 698; 7 Oct., 914
Graf-Apsco Co.
1959: 13 Nov., 1363
1960: 5 Feb., 365; 18 Mar., 879; 16 Sept., 747
Hacker, William J., & Co., Inc.
1959: 23 Oct., 1010
1960: 22 Jan., 185; 19 Feb., 449; 22 Apr., 1126; 26 Aug., 500; 23 Sept., 763
Lafayette Radio
1959: 23 Oct., 1012

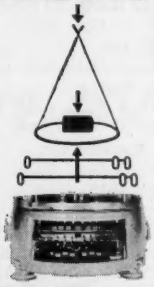
EASIEST TO OPERATE



Lowered recessed reading scale eliminates glare. Situated for maximum reading ease in line of vision with load pan.

SAUTER
Monopan
ANALYTICAL BALANCE

EXCLUSIVE
Monopan weights are in the bottom. Unlike other balances with weights on top, Monopan has no unnecessary swing. With Monopan, all downward force is compensated by equal upward thrust. Since weights are situated within the angle prescribed by pan, oscillation is minimized.



A single pan Analytical Balance making most efficient use of the reliable principle of substitution weighing for the determination of mass.
Very precise • Extremely stable • Remarkably simple.
Several exclusive features:

- Three position arrestment system provides positive locking of weight exchange in "free weighing" position.
- Load pan and substitution weights on separate stirrups minimize oscillation.
- Suspended side sliding doors. No dust-trapping grooves.
- No obstructive front corner posts.
- All controls at base. Operator can rest and steady forearm on table.

Cap.	200 grams
Tare Cap. (add.)	30 grams
Range of opt. scale	110 mg
Readability (per vernier div.)	0.1 mg
Accuracy diff. weighings within opt. range	0.03 mg
Size:	10½" x 18" x 18"
Net Wt.:	45 lbs.
Shipping Wt.:	57 lbs.

Write for Illustrated Literature

AUGUST SAUTER OF N.Y., INC.
866 WILLIS AVENUE
ALBERTSON, L. I., N. Y.
Pioneer 6-0254

Leitz, E., Inc.
1959: 2 Oct., 818; 16 Oct., 938; 6 Nov., 1210; 20 Nov., 1374; 27 Nov., 1444; 18 Dec., 1674
1960: 1 Jan., 2; 15 Jan., 122; 5 Feb., 314; 18 Mar., 752; 1 Apr., 950; 15 Apr., 1062; 6 May, 1334; 17 June, 1754; 1 July, 2; 15 July, 106; 19 Aug., 434; 2 Sept., 582
Lumiscope Co.
1959: 23 Oct., 1129; 4 Dec., 1597
United Scientific Co.
1959: 23 Oct., 1076; 11 Dec., 1616; 18 Dec., 1713
1960: 22 Jan., 176; 29 July, 264
Wild Heerbrugg Instruments, Inc.
1959: 23 Oct., 1046; 6 Nov., 1218; 20 Nov., 1435; 4 Dec., 1530
1960: 8 Jan., 68; 22 Jan., 230; 26 Feb., 614; 11 Mar., 694; 18 Mar., 796; 22 Apr., 1260; 13 May, 1400; 10 June, 1700; 24 June, 1858; 8 July, 95; 22 July, 250; 19 Aug., 486; 26 Aug., 552; 9 Sept., 685; 23 Sept., 828
Zeiss, Carl, Inc.
1959: 9 Oct., 893; 23 Oct., 1023; 13 Nov., 1288
1960: 26 Feb., 621; 18 Mar., 789; 13 May, 1459; 5 Aug., 371

MICROSCOPES, ELECTRON

Bendix Aviation Corp., Cincinnati Div.
1959: 23 Oct., 1123; 4 Dec., 1601
1960: 22 Jan., 243; 22 July, 233
Erb & Gray Scientific, Inc.
1959: 4 Dec., 1522; 11 Dec., 1663
1960: 22 Jan., 188; 19 Feb., 549; 4 Mar., 673; 18 Mar., 853; 27 May, 1629; 8 July, 97; 26 Aug., 565; 23 Sept., 833
Hitachi, Ltd.
1960: 26 Feb., 615; 25 Mar., 939; 15 July, 155
National Instrument Laboratories, Inc.
1960: 23 Sept., 758
Philips Electronics, Inc.
1959: 23 Oct., 1040; 4 Dec., 1526
1960: 18 Mar., 780; 22 Apr., 1136
Siemens New York, Inc.
1959: 23 Oct., 1155; 4 Dec., 1611

MICROSCOPES, POLARIZING

American Optical Co.
1960: 8 Apr., 1060; 12 Aug., 432
Leitz, E., Inc.
1960: 5 Aug., 314
United Scientific Co.
1959: 27 Nov., 1484
1960: 15 Jan., 168; 26 Feb., 616; 8 Apr., 1054; 3 June, 1688; 8 July, 98; 12 Aug., 427; 2 Sept., 626
Zeiss, Carl, Inc.
1960: 8 July, 56

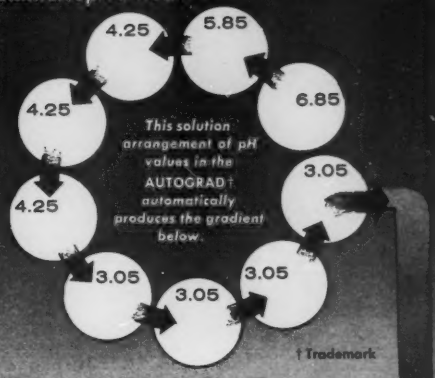
MICROSCOPES, STEREO

American Optical Co.
1959: 23 Oct., 1156
1960: 1 Jan., 52; 25 Mar., 948; 6 May, 1392; 23 Sept., 856
Bausch & Lomb Optical Co.
1959: 23 Oct., 1050; 20 Nov., 1382; 4 Dec., 1534
1960: 29 Jan., 268; 26 Feb., 578; 6 May, 1340; 1 July, 8; 12 Aug., 386; 23 Sept., 784
Cooke, Troughton & Simms, Inc.
1960: 29 Apr., 1276; 20 May, 1469

TECHNICON
AUTOMATIC
VARIABLE
GRADIENT
DEVICE*
produces any buffer requirement in *pH* or concentration for chromatography

Eliminates
DISCRETE BUFFER CHANGEOVERS
as an example . . .

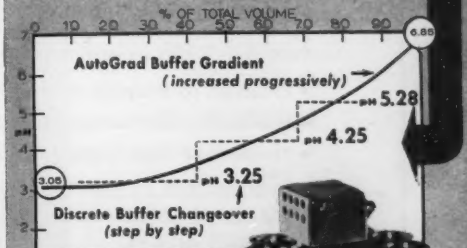
to pH 5.28
to pH 4.25
from pH 3.25 . . . *usual in*
AMINO ACID CHROMATOGRAPHY
*instead the Autograd automatically supplies a buffer gradient in a continuous, uninterrupted flow.***



† Trademark

Produces higher Resolution

The Autograd† starts the column elution delivery at *pH* 3.05, as shown above, and progressively in a continuous flow, increases to *pH* 6.85. Not only is each discrete buffer value systematically produced, but the resulting gradient includes *all* of the intermediate values as graphed below.



Developed at the National Cancer Institute, National Institutes of Health, U. S. Department of Health, Education, and Welfare, Public Health Service, Bethesda, Maryland.
***Procedure developed by *Karl A. Piez, National Institute of Dental Research, National Institute of Health.*
Reference: "Variable Gradient Device for Chromatography", E. A. Peterson and H. A. Sober, Anal. Chem., Vol. 31, No. 34, May 1959.

Send for Brochure No. AG1, and further Data, to:
Technicon Chromatography Corp.
Research Park · Chauncey, New York

Edmund Scientific Co.
1959: 9 Oct., 886; 6 Nov., 1221
1960: 8 Jan., 69; 19 Feb., 459; 27 May, 1631; 17 June, 1764; 22 July, 259; 26 Aug., 508; 23 Sept., 855
Sobotka, Eric, Co.
1960: 13 May, 1450; 20 May, 1540; 3 June, 1686; 9 Sept., 688; 23 Sept., 845; 7 Oct., 964
United Scientific Co.
1959: 2 Oct., 871; 20 Nov., 1432
1960: 22 Jan., 176; 12 Feb., 425; 11 Mar., 744; 18 Mar., 754; 15 Apr., 1064; 29 Apr., 1327; 10 June, 1747; 22 July, 233; 26 Aug., 572; 23 Sept., 756; 7 Oct., 970
Wild Heerbrugg Instruments, Inc.
1959: 9 Oct., 890
1960: 29 Jan., 263; 12 Feb., 380; 27 May, 1627; 12 Aug., 378

MICROSCOPES, STUDENT

Bausch & Lomb Optical Co.
1960: 22 Apr., 1164; 3 June, 1640; 23 Sept., 784
Edmund Scientific Co.
1959: 27 Nov., 1446; 4 Dec., 1506
1960: 19 Feb., 459
Elgeet Optical Co., Inc., Scientific Instrument and Apparatus Div.
1959: 13 Nov., 1301
1960: 22 Jan., 186; 18 Mar., 793; 20 May, 1487; 10 June, 1699; 22 July, 185; 5 Aug., 318; 19 Aug., 491; 2 Sept., 631; 16 Sept., 698; 7 Oct., 914
Graf-Apsco Co.
1959: 23 Oct., 1121; 4 Dec., 1595
1960: 22 Jan., 237; 19 Feb., 563; 22 Apr., 1244; 20 May, 1549; 9 Sept., 686; 23 Sept., 816
Leitz, E. Inc.
1959: 23 Oct., 1033; 18 Dec., 1674
Science Materials Center
1959: 6 Nov., 1217
United Scientific Co.
1959: 23 Oct., 1076, 1077; 13 Nov., 1280
1960: 19 Feb., 436; 4 Mar., 677; 1 Apr., 996; 18 Mar., 754; 15 Apr., 1064; 22 Apr., 1246; 13 May, 1454; 20 May, 1562; 27 May, 1576; 24 June, 1852; 15 July, 156; 29 July, 264; 19 Aug., 436; 16 Sept., 748; 30 Sept., 902

MICROSCOPES, TELEVISION

Brinkmann Instruments, Inc.
1960: 19 Feb., 467; 18 Mar., 774

MICROSCOPE ACCESSORIES

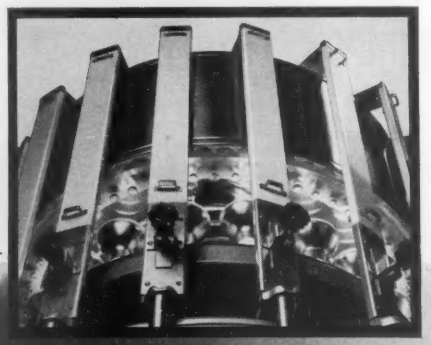
American Hospital Supply Corp.
1960: 19 Feb., 458
American Optical Co.
1959: 20 Nov., 1440
1960: 12 Feb., 432; 26 Feb., 622; 8 Apr., 1060; 6 May, 1392; 17 June, 1848; 1 July, 52; 26 Aug., 580; 23 Sept., 856; 7 Oct., 976
Burton Manufacturing Co.
1959: 23 Oct., 1152
Hacker, William J., & Co., Inc.
1960: 22 Apr., 1126
Lafayette Radio
1959: 23 Oct., 1012
Leitz, E., Inc.
1959: 16 Oct., 938
Sobotka, Eric, Co.
1960: 26 Feb., 616; 18 Mar., 842; 8 Apr., 1054
United Scientific Co.
1959: 23 Oct., 1076; 13 Nov., 1280; 11 Dec., 1616
1960: 12 Feb., 425; 19 Feb., 436; 11 Mar., 744; 18 Mar., 754; 15 Apr., 1064; 29 Apr., 1327; 27 May, 1576; 24 June, 1852; 29 July, 264; 19 Aug., 436; 26 Aug., 572; 23 Sept., 756; 7 Oct., 970
Wild Heerbrugg Instruments, Inc.
1959: 23 Oct., 1046; 18 Dec., 1678
1960: 8 Jan., 68; 22 Apr., 1260; 13 May, 1400; 8 July, 95; 22 July, 250; 19 Aug., 486; 9 Sept., 685; 23 Sept., 828
Zeiss, Carl, Inc.
1960: 15 Jan., 127

MICROSCOPE SLIDES

Erie Scientific Co.
1960: 22 Apr., 1250
National Instrument Laboratories, Inc.
1960: 18 Mar., 760

MICROTOMES AND ACCESSORIES

American Optical Co.
1959: 9 Oct., 936; 4 Dec., 1612; 18 Dec., 1724
1960: 20 May, 1572; 29 July, 312; 9 Sept., 692
Brunswick-Balke-Collender Co., Aloe Scientific Div.
1959: 16 Oct., 987
Hacker, William J., & Co., Inc.
1960: 18 Mar., 858



PHOTOSYNTHESIS

WARBURG APPARATUS

by GME

This version of the GME-Lardy Circular Warburg apparatus has a specially constructed water bath with a transparent plastic bottom. 30-watt reflector spotlights are suitably placed beneath the bath, providing 1000 to 1400 foot-candles on each flask.

- Excursion continuously variable from 0 to 5 cm.
- Shaking rate continuously variable from 75 to 150 per minute
- Temperature range ambient to 50° C.
- Accommodates 18 manometers, 16 of them with lights
- Accurate temperature control, better than ±.02° C.
- Diameter: 26 inches

Unlimited rotation when lights are not used. Refrigerated models also available, as well as a somewhat smaller model with accommodations for 14 manometers, 12 of them with lights.

Gilson Medical Electronics
Middleton, Wisconsin
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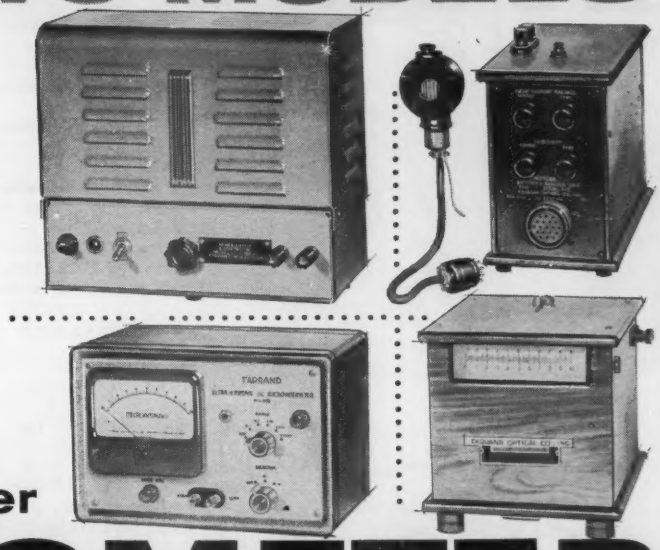

Farrand Electron Multiplier PHOTOMETER

Technical data available on request specify Bulletin No. 804S

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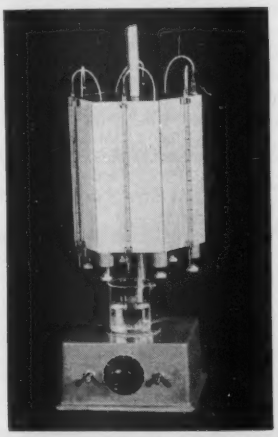

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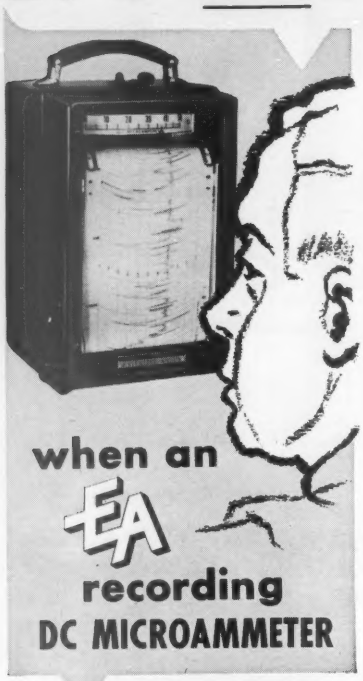

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Lafayette Radio
1959: 23 Oct., 1013
Leitz, E., Inc.
1959: 9 Oct., 889
1960: 19 Feb., 434; 3 June, 1634; 16 Sept., 694
LKB Instruments, Inc.
1960: 22 Jan., 190; 29 Jan., 311; 26 Feb., 615; 18 Mar., 873
National Instrument Laboratories, Inc.
1959: 23 Oct., 1032
1960: 18 Mar., 760
Schueler & Co., Schuco Scientific Div.
1960: 9 Sept., 689; 23 Sept., 839
Sorvall, Ivan, Inc.
1959: 23 Oct., 1025
1960: 15 Jan., 170; 22 Apr., 1128; 20 May, 1561; 22 July, 231; 26 Aug., 567

MICRO-WAVE APPARATUS

Central Scientific Co.
1959: 16 Oct., 988
Raytheon Co.
1959: 9 Oct., 892; 16 Oct., 991; 23 Oct., 1044; 30 Oct., 1162; 13 Nov., 1302; 27 Nov., 1482; 18 Dec., 1719
1960: 22 Jan., 192; 19 Feb., 452; 18 Mar., 770; 22 Apr., 1148; 20 May, 1480, 1553; 17 June, 1772, 1829; 22 July, 184, 241; 26 Aug., 512, 561; 23 Sept., 772

MIXERS

Brunswick-Balke-Collender Co., Aloe Scientific Div.
1960: 22 Apr., 1265; 20 May, 1555
Buchler Instruments, Inc., formerly Laboratory Glass & Instrument Corp.
1960: 22 Jan., 180; 19 Feb., 460; 22 Apr., 1226
Heller, Gerald K., Co.
1960: 18 Mar., 843; 22 Apr., 1258; 20 May, 1542; 22 July, 239; 23 Sept., 830
Scientific Industries, Inc.
1960: 16 Sept., 748

MOLECULAR MODEL SETS

LaPine, Arthur S., and Co.
1960: 23 Sept., 822
Will Corp., Bronwill Scientific Div.
1960: 18 Mar., 864; 8 Apr., 1055; 9 Sept., 680

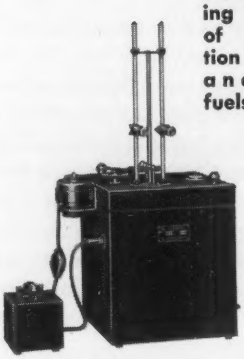
MONOCHROMATORS

Bausch & Lomb Optical Co.
1960: 11 Mar., 698
Farrand Optical Co., Inc.
1959: 13 Nov., 1351; 4 Dec., 1583
1960: 19 Feb., 563; 17 June, 1815; 7 Oct., 965
Perkin-Elmer Corp., Instrument Div.
1959: 4 Dec., 1496
1960: 15 Jan., 124
Photovolt Corp.
1959: 2 Oct., 867
1960: 1 Jan., 51; 4 Mar., 673; 29 Apr., 1324; 3 June, 1687; 5 Aug., 367

NEPHELOMETERS

Klett Manufacturing Co.
1960: 26 Feb., 618; 18 Mar., 843; 25 Mar., 945; 8 Apr., 1051; 29 Apr., 1325; 6 May, 1384; 20 May, 1552; 3 June, 1687; 1 July, 47; 8 July, 94; 29 July, 311; 12 Aug., 429; 19 Aug., 477; 16 Sept., 747; 23 Sept., 850; 7 Oct., 973

Series 1200
PARR Calorimeter



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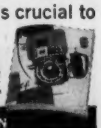

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Thomas, Arthur H., Co.
1960: 22 July, 260; 16 Sept., 752
Will Corp.
1960: 19 Feb., 561

NEUTRON GENERATORS

Central Scientific Co.
1959: 20 Nov., 1431
1960: 19 Feb., 549
Kaman Aircraft Corp., Nuclear Div.
1959: 4 Dec., 1528
Texas Nuclear Corp.
1960: 18 Mar., 877

NUCLEAR LABORATORY INSTRUMENTS

Anton Electronic Laboratories, Inc.
1960: 23 Sept., 759
Baird-Atomic, Inc.
1959: 4 Dec., 1508
1960: 19 Feb., 468; 20 May, 1515
Budd Co., Nuclear Systems Div.
1959: 4 Dec., 1498
Johnston, William H., Laboratories, Inc.
1960: 17 June, 1834
Nuclear-Chicago Corp.
1959: 27 Nov., 1492
1960: 22 Jan., 260; 19 Feb., 570; 4 Mar., 682
Packard Instrument Co., Inc.
1959: 16 Oct., 946
Picker X-Ray Corp.
1959: 23 Oct., 1015
1960: 18 Mar., 775; 17 June, 1775
Radiation Counter Laboratories, Inc.
1960: 19 Feb., 545
Radiation Instrument Development Laboratory, Inc.
1960: 19 Feb., 473; 7 Oct., 964
Technical Associates
1960: 18 Mar., 865
Technical Measurement Corp.
1959: 23 Oct., 1048; 20 Nov., 1380; 4 Dec., 1532
Tracerlab, Inc.
1960: 23 Sept., 760
Vanguard Instrument Co.
1960: 26 Aug., 506
Victoreen Instrument Co.
1960: 22 Jan., 252

OPTICAL CRYSTALS

Harshaw Chemical Co.
1959: 2 Oct., 869; 4 Dec., 1595
1960: 19 Feb., 539; 8 Apr., 1055; 10 June, 1747; 19 Aug., 477; 7 Oct., 965
Isomet Corp.
1959: 23 Oct., 1139; 4 Dec., 1601
1960: 18 Mar., 883; 20 May, 1552

OSCILLATORS, SONIC

Raytheon Co.
1960: 22 Jan., 241; 19 Feb., 551; 18 Mar., 869; 22 Apr., 1237; 23 Sept., 837

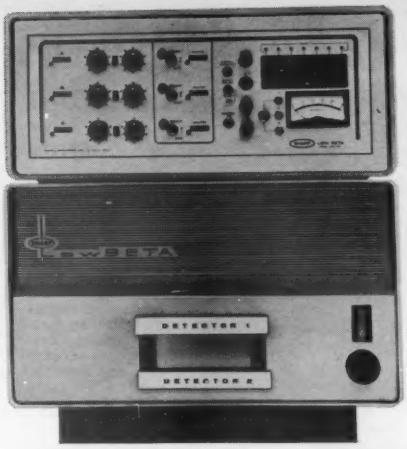
OSMOMETERS

Rosemount Engineering Co.
1960: 22 Apr., 1244

OVENS

Boeckel, Wm., & Co., Inc.
1960: 20 May, 1537
Central Scientific Co.
1960: 29 July, 311

LOW BACKGROUND BETA COUNTING SYSTEM



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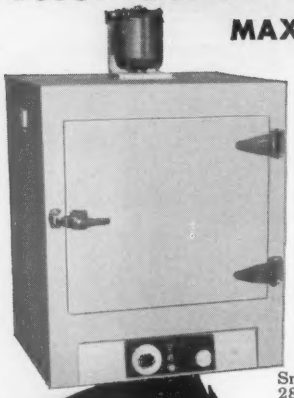

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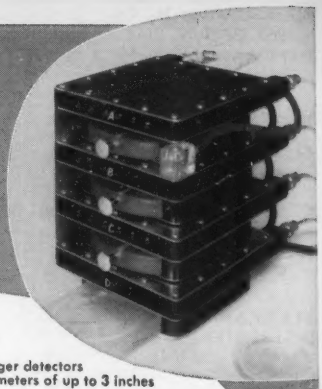

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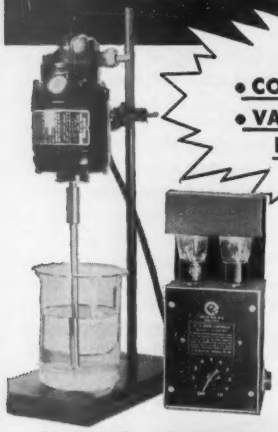

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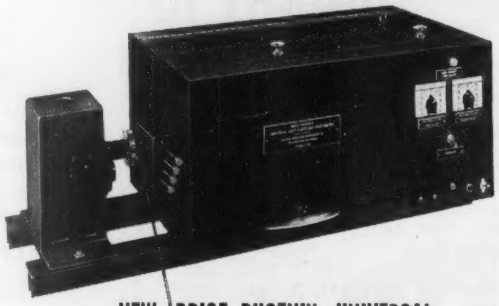

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3. Depolarization

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Fisher Scientific Co.
1960: 22 Apr., 1160
National Appliance Co.
1959: 23 Oct., 1118; 13 Nov., 1353
1960: 8 Jan., 111
New Brunswick Scientific Co., Inc.
1959: 23 Oct., 1123; 11 Dec., 1666
1960: 5 Feb., 367; 13 May, 1452; 24 June, 1896; 23 Sept., 849
New York Laboratory Supply Co., Inc.,
1960: 18 Mar., 863; 17 June, 1819
Precision Scientific Co.
1959: 13 Nov., 1352; 4 Dec., 1588
1960: 26 Aug., 568
Research Specialties Co.
1959: 23 Oct., 1043
Sargent, E. H., & Co.
1959: 2 Oct., 820
1960: 22 July, 188

*p*H METERS

American Hospital Supply Corp.
1960: 24 June, 1857
Beckman Instruments, Inc., Scientific and Process Instruments Div.
1959: 16 Oct., 943; 18 Dec., 1676
1960: 5 Feb., 321; 15 Apr., 1069; 17 June, 1763; 15 July, 163
Brinkman, C. A., & Co., Inc.
1959: 6 Nov., 1219; 13 Nov., 1363
1960: 22 Jan., 215, 217, 218; 29 Jan., 307; 4 Mar., 678; 8 Apr., 1004
Cambridge Instrument Co., Inc.
1959: 23 Oct., 1150
Coleman Instruments, Inc.
1959: 4 Dec., 1515
1960: 22 Jan., 181; 20 May, 1483
Harshaw Chemical Co., Harshaw Scientific Div.
1960: 18 Mar., 848; 20 May, 1538
Photovolt Corp.
1959: 11 Dec., 1663
1960: 22 Jan., 251; 11 Mar., 747; 8 Apr., 1055; 13 May, 1457; 27 May, 1628; 15 July, 160; 16 Sept., 749
Riseman Development Laboratory
1960: 23 Sept., 850
Scientific Glass Apparatus Co., Inc.
1960: 25 Mar., 942; 22 Apr., 1242; 20 May, 1477
Thomas, Arthur H., Co.
1960: 19 Aug., 492
Welwyn International Inc.
1959: 23 Oct., 1036; 13 Nov., 1286
1960: 22 Jan., 259; 22 Apr., 1144; 20 May, 1478; 23 Sept., 778

PHOTOMETERS

Farrand Optical Co., Inc.
1960: 20 May, 1539
Phoenix Precision Instrument Co.
1960: 19 Feb., 599; 20 May, 1552; 23 Sept., 849
Photovolt Corp.
1960: 29 Jan., 307; 5 Feb., 367; 25 Mar., 943; 6 May, 1386; 10 June, 1749; 29 July, 311; 12 Aug., 425; 9 Sept., 681; 30 Sept., 904; 7 Oct., 967
Welch, W. M., Manufacturing Co.
1960: 7 Oct., 967

PHOTOMETERS, FLAME

Baird-Atomic, Inc.
1959: 23 Oct., 1145
1960: 22 Jan., 248; 19 Feb., 554; 18 Mar., 856; 22 Apr., 1256; 20 May, 1548; 17 June, 1839; 22 July, 238; 26 Aug., 574; 23 Sept., 850
Coleman Instruments, Inc.
1959: 23 Oct., 1047
1960: 17 June 1774; 26 Aug., 502
Perkin-Elmer Corp.
1959: 23 Oct., 1000
Will Corp.
1960: 23 Sept., 815

PHOTOMICROGRAPHIC EQUIPMENT

Aloe, A. S., Co., Aloe Scientific Div.
1960: 1 Jan., 48
American Optical Co.
1959: 6 Nov., 1276
1960: 15 Jan., 172; 22 Apr., 1272; 6 May, 1392; 15 July, 164
Bausch & Lomb Optical Co.
1960: 26 Feb., 578
Hacker, William J., & Co., Inc.
1960: 22 Jan., 185; 19 Feb., 449; 23 Sept., 763
Leitz, E., Inc.
1959: 2 Oct., 818; 16 Oct., 938; 20 Nov., 1374; 27 Nov., 1444
1960: 1 Jan., 2; 15 Jan., 122; 5 Feb., 314
Photovolt Corp.
1959: 16 Oct., 987
1960: 5 Feb., 367; 25 Mar., 943; 10 June, 1749; 12 Aug., 425; 30 Sept., 904
United Scientific Co.
1959: 23 Oct., 1076; 13 Nov., 1280
1960: 22 Jan., 176; 29 Jan., 304; 25 Mar., 940; 17 June, 1840; 24 June, 1852; 29 July, 264; 9 Sept., 683; 23 Sept., 756
Zeiss, Carl, Inc.
1959: 23 Oct., 1023
1960: 15 Jan., 127

PLASMA GENERATORS

Avco Corp., Research and Advanced Development Div.
1959: 2 Oct., 827

POLARIMETERS

Kern Co.
1960: 7 Oct., 964
Leitz, E., Inc.
1959: 4 Dec., 1529
1960: 4 Mar., 624
Photovolt Corp.
1959: 23 Oct., 1137; 11 Dec., 1663
1960: 8 Jan., 116; 1 July, 47
Rudolph Instruments Engineering Co.
1959: 23 Oct., 1034
Zeiss, Carl, Inc.
1959: 9 Oct., 893
1960: 19 Feb., 455; 3 June, 1638; 8 July, 56; 9 Sept., 679

POLARISCOPES

Bethlehem Apparatus Co., Inc.
1960: 23 Sept., 848

POLAROGRAPHS

Brinkmann, C. A., & Co.
1960: 22 Jan., 216; 29 Apr., 1327; 3 June, 1685; 15 July, 155
Fisher Scientific Co.
1960: 19 Feb., 475
Sargent, E. H., & Co.
1960: 22 Jan., 193; 20 May, 1485; 15 July, 111; 26 Aug., 505
Welwyn International, Inc.
1960: 18 Mar., 790

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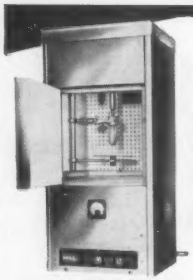

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POTENTIOMETERS, SLIDEWIRE

B & H Instrument Co., Inc.
1959: 23 Oct., 1031

POWER GENERATORS

Raytheon Co.
1959: 9 Oct., 892; 16 Oct., 991; 23 Oct., 1044; 30 Oct., 1162; 13 Nov., 1302; 27 Nov., 1482; 18 Dec., 1719
1960: 22 Jan., 192; 19 Feb., 452; 18 Mar., 770; 22 Apr., 1148; 20 May, 1480, 1553; 17 June, 1772, 1829; 22 July, 184, 241; 26 Aug., 512, 561; 23 Sept., 772

POWER SUPPLIES

American Electronic Laboratories, Inc.
1959: 23 Oct., 1139
1960: 18 Mar., 778
Fluke, John, Manufacturing Co., Inc.
1960: 26 Aug., 503
Harvey-Wells Electronics, Inc.
1960: 17 June, 1825
Sorensen & Co.
1960: 19 Feb., 541; 18 Mar., 866; 20 May, 1468; 26 Aug., 555; 23 Sept., 841
Zeiss, Carl, Inc.
1959: 4 Dec., 1525
1960: 7 Oct., 975

PRESSURE APPARATUS

Parr Instrument Co.
1959: 23 Oct., 1135
1960: 22 Jan., 242; 22 July, 242

PRIMATE RESTRAINT SYSTEMS

Foringer & Co., Inc.
1960: 7 Oct., 971

PROGRAMMERS, AUTOMATIC

Foringer & Co., Inc.
1959: 4 Dec., 1603

PROJECTORS

Bausch & Lomb Optical Co.
1959: 23 Oct., 1050; 6 Nov., 1224; 4 Dec., 1534
1960: 29 Jan., 268; 26 Feb., 578; 20 May, 1492; 3 June, 1640; 1 July, 8
Edmund Scientific Co.
1959: 9 Oct., 886; 6 Nov., 1221; 27 Nov., 1446; 4 Dec., 1506
1960: 19 Feb., 459; 18 Mar., 791; 22 Apr., 1138; 27 May, 1631; 22 July, 259
Leitz, E., Inc.
1959: 13 Nov., 1293
1960: 20 May, 1462; 7 Oct., 910

PUMPS

Eastern Industries, Inc.
1959: 13 Nov., 1296
1960: 18 Mar., 840; 17 June, 1830; 23 Sept., 838
Harvard Apparatus Co., Inc.
1959: 23 Oct., 1139
1960: 22 Apr., 1261; 22 July, 239
Phipps & Bird, Inc.
1960: 18 Mar., 853; 22 July, 254; 29 July, 309; 2 Sept., 629; 9 Sept., 686
Sigmamotor, Inc.
1959: 23 Oct., 1132; 4 Dec., 1604
1960: 8 Apr., 1053

PUMPS, VACUUM

Central Scientific Co.
1960: 25 Mar., 941
Hevi-Duty Electric Company
1960: 8 Jan., 111; 4 Mar., 677
LaPine, Arthur S., and Co.
1960: 18 Mar., 842; 20 May, 1550
New York Air Brake Co., Kinney Vacuum Div.
1960: 19 Feb., 533; 18 Mar., 849; 22 Apr., 1225; 17 June, 1819; 19 Aug., 483
Precision Scientific Co.
1960: 17 June, 1828; 22 July, 230; 23 Sept., 840
Welch, W. M., Manufacturing Co.
1959: 6 Nov., 1267

RADIATION COUNTERS

Amperex Electronic Corp.
1959: 23 Oct., 1029
Atomic Accessories, Inc.
1959: 4 Dec., 1591
Johnston, William H., Laboratories, Inc.
1960: 17 June, 1834
Nuclear-Chicago Corp.
1959: 16 Oct., 996; 11 Dec., 1672
1960: 1 Apr., 1000; 13 May, 1460; 10 June, 1752; 8 July, 104; 5 Aug., 372; 2 Sept., 632
Packard Instrument Co., Inc.
1959: 16 Oct., 946
Picker X-Ray Corp.
1959: 23 Oct., 1015; 13 Nov., 1304; 11 Dec., 1619
1960: 22 Jan., 187; 19 Feb., 461; 18 Mar., 775; 20 May, 1489; 12 Aug., 379; 23 Sept., 775
Radiation Counter Laboratories, Inc.
1960: 19 Feb., 545; 22 Apr., 1235
Radiation Instrument Development Laboratory, Inc.
1960: 7 Oct., 964
Technical Associates
1960: 18 Mar., 865; 20 May, 1563; 22 July, 247
Technical Measurement Corp.
1959: 9 Oct., 894
1960: 22 Apr., 1162; 15 July, 112; 26 Aug., 516
Tracerlab, Inc.
1960: 19 Feb., 448; 23 Sept., 760
Victoreen Instrument Co.
1960: 17 June, 1755

RADIOACTIVE WASTE CONTAINER

Blickman, S., Inc.
1960: 23 Sept., 830

RATEMETERS

Packard Instrument Co., Inc.
1960: 29 Apr., 1286; 10 June, 1704; 5 Aug., 322; 16 Sept., 706
Picker X-Ray Corp.
1960: 19 Feb., 461; 22 Apr., 1151; 20 May, 1489; 15 July, 107; 12 Aug., 379; 23 Sept., 775
Radiation Instrument Development Laboratory, Inc.
1960: 7 Oct., 964

READERS, STRIP CHART

Benson-Lehner Corp.
1960: 19 Feb., 440; 18 Mar., 777

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REAGENTS

Allied Chemical Co.
1960: 22 Jan., 240; 23 Sept., 755
Baker, J. T., Co.
1959: 23 Oct., 1030; 13 Nov., 1352; 4 Dec., 1503
1960: 8 Jan., 65; 18 Mar., 767; 22 Apr., 1124; 20 May, 1535; 10 June, 1740
Borden Chemical Co.
1959: 4 Dec., 1584; 25 Dec., 1728
Colorado Serum Co.
1959: 4 Dec., 1597
1960: 15 Jan., 165; 9 Sept., 681
Difco Laboratories
1959: 13 Nov., 1351; 18 Dec., 1713
1960: 18 Mar., 853; 22 Apr., 1221; 22 July, 239; 26 Aug., 563
Eastern Chemical Corp.
1960: 7 Oct., 971
Hyland Laboratories
1959: 4 Dec., 1587
Klett Manufacturing Co.
1959: 9 Oct., 931; 30 Oct., 1202; 6 Nov., 1269; 4 Dec., 1597; 11 Dec., 1665; 25 Dec., 1767
1960: 1 Jan., 47; 8 Jan., 115; 15 Jan., 165; 29 Jan., 305; 12 Feb., 425; 19 Feb., 545; 26 Feb., 618; 11 Mar., 747; 25 Mar., 945; 8 Apr., 1051; 15 Apr., 1106; 22 Apr., 1236; 6 May, 1384; 13 May, 1452; 3 June, 1687; 17 June, 1833; 24 June, 1896; 8 July, 94; 22 July, 254; 5 Aug., 369; 12 Aug., 429; 26 Aug., 575; 2 Sept., 628; 23 Sept., 850; 30 Sept., 905; 7 Oct., 973
Mallinckrodt Chemical Works
1959: 23 Oct., 1002, 1003
Matheson Co., Inc.
1959: 23 Oct., 1124
Nuclear-Chicago Corp.
1959: 16 Oct., 996
Schueler and Co., Schuco Scientific Div.
1960: 19 Feb., 565; 23 Sept., 814
Scientific Glass Apparatus Co., Inc.
1959: 23 Oct., 1026
Sigma Chemical Co.
1959: 9 Oct., 931
Worthington Biochemical Corp.
1960: 1 Jan., 48

RECORDERS, GRAPHIC

American Hospital Supply Corp.
1960: 6 May, 1338; 12 Aug., 431
Atomic Accessories, Inc.
1960: 23 Sept., 812
Beckman Instruments, Inc., Scientific and Process Instruments Div.
1960: 19 Aug., 485
Brinkmann, C. A., & Co.
1960: 22 Jan., 216
Esterline-Angus Co.
1959: 13 Nov., 1364; 4 Dec., 1584
1960: 22 Jan., 238; 18 Mar., 850; 22 Apr., 1229; 20 May, 1540; 17 June, 1837; 22 July, 250; 26 Aug., 554; 23 Sept., 826
Fisher Scientific Co.
1960: 19 Feb., 475; 18 Mar., 780; 26 Aug., 510
Harshaw Chemical Co., Harshaw Scientific Div.
1960: 16 Sept., 746
Houston Instrument Corp.
1960: 22 July, 230; 23 Sept., 844
Nesco Instruments, Inc.
1960: 26 Aug., 569
Offner Electronics, Inc.
1960: 24 June, 1894; 15 July, 110; 19 Aug., 487
Photovolt Corp.
1959: 9 Oct., 929; 20 Nov., 1431
1960: 29 Jan., 307; 12 Feb., 425
Sargent, E. H., & Co.
1959: 23 Oct., 1045; 27 Nov., 1491; 4 Dec., 1577
1960: 22 Jan., 193; 19 Feb., 464; 22 Apr., 1158; 20 May, 1485; 17 June, 1847
Smith, Arthur F., Inc.
1960: 7 Oct., 968
Stoelting, C. H., Co.
1959: 2 Oct., 873; 23 Oct., 1144; 13 Nov., 1367; 4 Dec., 1604
1960: 8 Jan., 115; 19 Feb., 559; 18 Mar., 873; 22 Apr., 1258; 17 June, 1833; 7 Oct., 970
Texas Instruments, Inc.
1960: 18 Mar., 887; 17 June, 1768; 23 Sept., 813
Welwyn International, Inc.
1960: 18 Mar., 790
Yellow Springs Instrument Co., Inc.
1960: 18 Mar., 838; 20 May, 1560; 23 Sept., 818

RECORDING EQUIPMENT, BIOPHYSICAL

Epsco, Inc., Epsco Worcester Div.
1960: 18 Mar., 871
Gilson Medical Electronics
1959: 9 Oct., 931; 23 Oct., 1144
1960: 8 Apr., 1051; 13 May, 1455; 12 Aug., 429
Precision Instrument Co.
1960: 17 June, 1822; 22 July, 255
Sanborn Co., Medical Div.
1959: 13 Nov., 1294
1960: 8 Jan., 62; 5 Feb., 371

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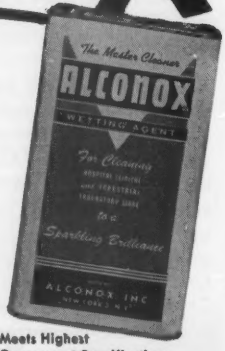

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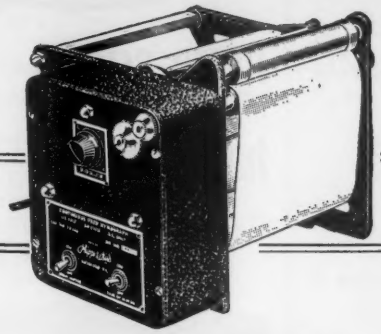

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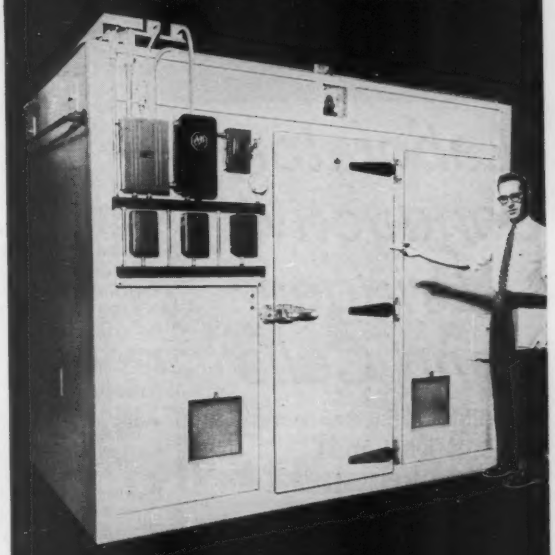

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REFRACTOMETERS

Lafayette Radio
1959: 23 Oct., 1012, 1013
Leitz, E., Inc.
1959: 4 Dec., 1529
1960: 4 Mar., 624
Phoenix Precision Instrument Co.
1960: 19 Feb., 563; 20 May, 1542; 23 Sept., 839
Zeiss, Carl, Inc.
1960: 8 July, 56; 9 Sept., 679

REFRIGERATORS

Union Carbide Corp., Linde Co. Div.
1959: 23 Oct., 1130
1960: 19 Feb., 564; 18 Mar., 860; 17 June, 1836

SCALES

Brinkmann, C. A., & Co.
1960: 1 Apr., 954
Mettler Instrument Corp.
1960: 18 Mar., 779; 22 July, 235
Welch, W. M., Manufacturing Co.
1960: 6 May, 1385; 5 Aug., 367

SCALERS, NUCLEAR

Baird-Atomic, Inc.
1959: 4 Dec., 1505
1960: 17 June, 1765; 22 July, 173
Nuclear-Chicago Corp.
1960: 18 Mar., 865
Packard Instrument Co., Inc.
1959: 23 Oct., 1041; 11 Dec., 1628
1960: 22 Jan., 196; 29 Apr., 1286; 10 June, 1704; 5 Aug., 322; 16 Sept., 706
Picker X-Ray Corp.
1959: 13 Nov., 1304
1960: 22 Jan., 187; 19 Feb., 461; 15 July, 107; 12 Aug., 379; 23 Sept., 775
Radiation Counter Laboratories, Inc.
1960: 19 Feb., 545; 22 Apr., 1235
Radiation Instrument Development Laboratory, Inc.
1960: 23 Sept., 847
Technical Associates
1960: 5 Aug., 372
Technical Measurement Corp.
1959: 9 Oct., 894; 23 Oct., 1048
1960: 19 Feb., 476; 22 Apr., 1162; 13 May, 1404; 26 Aug., 516; 16 Sept., 704
Tracerlab, Inc.
1959: 23 Oct., 1037
1960: 17 June, 1770
Victoreen Instrument Co.
1959: 23 Oct., 1131; 13 Nov., 1304

SCINTILLATION CRYSTALS

Harshaw Chemical Co.
1959: 2 Oct., 869; 4 Dec., 1595
1960: 19 Feb., 539; 8 Apr., 1055; 10 June, 1747; 19 Aug., 477; 7 Oct., 965
Isomet Corp.
1959: 23 Oct., 1139
Pilot Chemicals, Inc.
1960: 19 Feb., 555; 22 Apr., 1258; 17 June, 1842; 26 Aug., 572

SHAKERS

New Brunswick Scientific Co., Inc.
1959: 9 Oct., 929; 16 Oct., 993; 30 Oct., 1202; 13 Nov., 1351; 20 Nov., 1432; 27 Nov., 1489; 4 Dec., 1581
1960: 1 Jan., 47; 22 Jan., 255; 29 Jan.,

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309; 12 Feb., 426; 19 Feb., 559; 18 Mar., 877; 22 Apr., 1235; 27 May, 1626; 10 June, 1747; 17 June, 1938
Palo Laboratory Supplies, Inc.
1960: 22 Apr., 1268

SHIELDS, LEAD

Instrument and Development Products Co., Inc.
1960: 18 Mar., 863
Instruments for Research and Industry
1960: 18 Mar., 878
Technical Associates
1960: 18 Mar., 865; 20 May, 1563; 22 July, 247

SIEVES

Custom Scientific Instruments, Inc.
1960: 22 Jan., 234; 22 July, 236; 23 Sept., 834
New York Laboratory Supply Co., Inc.
1960: 18 Mar., 863

SLIDE RULES

Edmund Scientific Co.
1960: 22 Apr., 1138; 17 June, 1764; 22 July, 259; 26 Aug., 508

SKELETON MODEL

Welch, W. M., Manufacturing Co.
1959: 4 Dec., 1589
1960: 1 July, 51

SPECTROMETERS

Baird-Atomic, Inc.
1959: 23 Oct., 1021
Bausch & Lomb Optical Co.
1960: 29 July, 268
Bendix Aviation Corp., Cincinnati Div.
1959: 13 Nov., 1355
1960: 19 Feb., 553; 18 Mar., 880; 20 May, 1567; 17 June, 1821; 26 Aug., 557
Farrand Optical Co., Inc.
1960: 22 Jan., 237
High Voltage Engineering Corp.
1960: 26 Feb., 576; 18 Mar., 798
Leitz, E., Inc.
1959: 4 Dec., 1529
1960: 4 Mar., 624
Nuclear-Chicago Corp.
1960: 1 Apr., 1000
Packard Instrument Co., Inc.
1959: 2 Oct., 830; 16 Oct., 946; 23 Oct., 1041; 13 Nov., 1306; 27 Nov., 1448; 11 Dec., 1628; 25 Dec., 1734
1960: 8 Jan., 72; 22 Jan., 196; 5 Feb., 328; 19 Feb., 478; 4 Mar., 634; 18 Mar., 800; 22 Apr., 1152; 13 May, 1406; 27 May, 1582; 24 June, 1862; 8 July, 60; 22 July, 190; 19 Aug., 440; 2 Sept., 590; 30 Sept., 864
Perkin-Elmer Corp., Instrument Div.
1959: 4 Dec., 1496
1960: 15 Jan., 124
Philips Electronics, Inc.
1959: 13 Nov., 1285
Picker X-Ray Corp.
1959: 23 Oct., 1015; 13 Nov., 1304
1960: 22 Jan., 187; 22 Apr., 1151
Radiation Instrument Development Laboratory, Inc.
1960: 23 Sept., 847
Technical Associates
1960: 20 May, 1563

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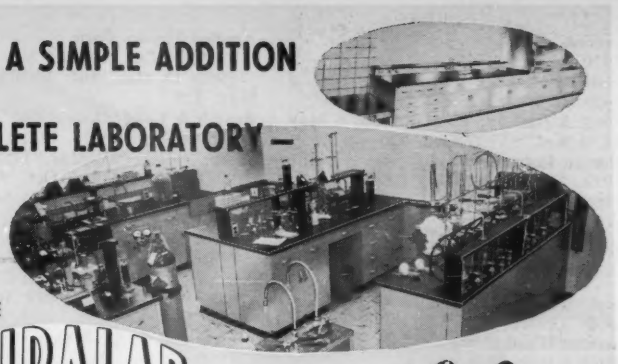

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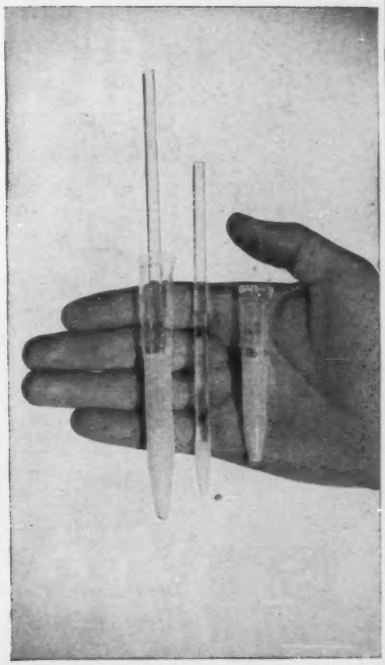

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Tracerlab, Inc.
1959: 23 Oct., 1037
Varian Associates
1959: 13 Nov., 1290
1960: 8 Jan., 58; 11 Mar., 696; 6 May, 1336; 9 Sept., 639; 7 Oct., 920
Victoreen Instrument Co.
1959: 23 Oct., 1131; 13 Nov., 1304
1960: 18 Mar., 784; 17 June, 1755

SPECTROPHOTOMETERS AND ACCESSORIES

American Electronic Laboratories, Inc.
1959: 23 Oct., 1139
American Hospital Supply Corp.
1960: 6 May, 1338
Applied Physics Corp.
1959: 23 Oct., 1119; 6 Nov., 1266
1960: 18 Mar., 867; 20 May, 1541; 23 Sept., 823
Bausch & Lomb Optical Co.
1960: 18 Mar., 772, 773; 25 Mar., 896; 8 Apr., 1014; 13 May, 1453; 17 June, 1780; 19 Aug., 479; 7 Oct., 924
Beckman Instruments, Inc., Scientific and Process Instruments Div.
1959: 20 Nov., 1379; 4 Dec., 1500, 1501
1960: 15 Jan., 128; 12 Feb., 379; 15 Apr., 1068; 22 Apr., 1125; 29 July, 305; 12 Aug., 383; 26 Aug., 499; 16 Sept., 699; 7 Oct., 915
Brinkmann, C. A., & Co.
1960: 22 Jan., 215
Brunswick-Balke-Collender Co., Aloe Scientific Div.
1959: 2 Oct., 868
Coleman Instruments, Inc.
1959: 23 Oct., 1047
1960: 8 Apr., 1008; 22 July, 182
Gilson Medical Electronics
1960: 8 Jan., 117
National Instrument Laboratories, Inc.
1959: 23 Oct., 1032
New York Laboratory Supply Co., Inc.
1959: 23 Oct., 1135
1960: 23 Sept., 843
Perkin-Elmer Corp., Instrument Div.
1959: 20 Nov., 1376; 4 Dec., 1496
1960: 29 Jan., 264; 11 Mar., 686; 20 May, 1464; 17 June, 1756; 16 Sept., 696
Scientific Glass Apparatus Co., Inc.
1960: 23 Sept., 832
Thomas, Arthur H., Co.
1960: 8 Jan., 120; 19 Feb., 472
Will Corp.
1960: 19 Feb., 561; 18 Mar., 847
Zeiss, Carl, Inc.
1960: 22 Apr., 1142

SPECTROSCOPES AND ACCESSORIES

Bausch & Lomb Optical Co.
1960: 26 Feb., 578; 3 June, 1640; 23 Sept., 784
Edmund Scientific Co.
1960: 8 Jan., 69; 18 Mar., 791
Fisher Scientific Co.
1960: 17 June, 1759
Isomet Corp.
1959: 4 Dec., 1601
1960: 18 Mar., 883
Lafayette Radio
1959: 23 Oct., 1013
Radio Corporation of America
1959: 23 Oct., 1018
Zeiss, Carl, Inc.
1959: 9 Oct., 893
1960: 8 July, 56; 9 Sept., 679

STERILIZERS

American Sterilizer Co.
1959: 23 Oct., 1009
1960: 19 Feb., 443; 22 July, 177
Hospital Supply Co., Inc.
1959: 23 Oct., 1142; 13 Nov., 1354; 4 Dec., 1592
Wilmot Castle Co.
1959: 23 Oct., 1039; 13 Nov., 1291
1960: 18 Mar., 764; 20 May, 1472; 26 Aug., 504; 2 Sept., 588

STILLS

American Sterilizer Co.
1960: 22 July, 177; 23 Sept., 761
Barnstead Still and Sterilizer Co.
1959: 23 Oct., 1042
1960: 18 Mar., 854; 22 Apr., 1248; 20 May, 1566; 26 Aug., 576
Smith, Arthur F., Co.
1959: 23 Oct., 1005
1960: 18 Mar., 758; 20 May, 1470; 23 Sept., 827

STIMULATORS

American Electronic Laboratories, Inc.
1959: 23 Oct., 1139; 4 Dec., 1581
1960: 22 Jan., 233; 18 Mar., 778; 23 Sept., 825
Harvard Apparatus Co., Inc.
1960: 19 Feb., 533

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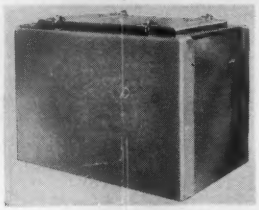
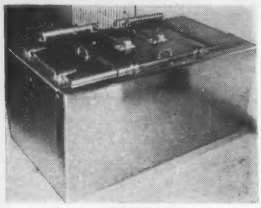


MODEL GS-34



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All cabinets are manufactured of welded and polished stainless steel which contributes to cleanliness, appearance and serviceability. Efficiency has been accounted for in such features as high quality insulation, interchangeable storage inserts and size. The width allows passage through a normal door and the length is the only dimension changed in the three sizes. The cabinets are built with or without the CO_2 entering the storage compartment. The cabinet on the left is our standard model and the unit on the right is specially constructed to the customer's design.

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STIRRERS

Ace Glass, Inc.
1960: 18 Mar., 855
Central Scientific Co.
1960: 26 Feb., 619; 22 Apr., 1236; 17 June, 1838
Eastern Industries, Inc.
1959: 13 Nov., 1296
1960: 18 Mar., 840; 17 June, 1830; 23 Sept., 838
Kontes Glass Co.
1959: 13 Nov., 1366
LaPine, Arthur S., and Co.
1960: 19 Feb., 560; 20 May, 1550
Smith, Arthur F., Inc.
1960: 22 Apr., 1253; 22 July, 251
Standard Scientific Supply Corp.
1960: 20 May, 1544; 26 Aug., 564
Thomas, Arthur H., Co.
1959: 4 Dec., 1494
Tri-R Instruments
1959: 23 Oct., 1137
1960: 22 Apr., 1258

STOPCOCKS AND ACCESSORIES

Ace Glass, Inc.
1960: 23 Sept., 829
Corning Glass Works
1960: 5 Feb., 322, 323; 3 June, 1636
Fischer & Porter Co.
1959: 13 Nov., 1287
1960: 22 Apr., 1137
Kimble Glass Co.
1959: 30 Oct., 1164; 6 Nov., 1222; 20 Nov., 1375; 4 Dec., 1519; 18 Dec., 1675
1960: 22 Jan., 183; 12 Feb., 381; 13 May, 1399; 10 June, 1701; 8 July, 58; 12 Aug., 381
Kontes Glass Co.
1959: 16 Oct., 985
Scientific Glass Apparatus Co., Inc.
1959: 11 Dec., 1662
1960: 19 Feb., 466
Thomas, Arthur H., Co.
1959: 13 Nov., 1372
Will Corp.
1960: 22 Apr., 1267; 27 May, 1625

STOPPERS

Thomas, Arthur H., Co.
1960: 27 May, 1632; 24 June, 1900

STOPWATCHES

Heuer Timer Corp.
1960: 22 Jan., 250

STORAGE CABINETS, DRY ICE

Custom Scientific Instruments, Inc.
1960: 18 Mar., 840; 20 May, 1546

STUDENT SCIENCE MATERIALS

American Electronic Laboratories, Inc.
1960: 23 Sept., 825
Atomic Associates, Inc.
1959: 4 Dec., 1505
Bausch & Lomb Optical Co.
1960: 26 Feb., 578; 22 Apr., 1164; 3 June, 1640; 23 Sept., 784
Central Scientific Co.
1959: 16 Oct., 988; 30 Oct., 1203; 13 Nov., 1368; 4 Dec., 1581; 11 Dec., 1666
1960: 15 Jan., 164; 22 Jan., 255; 12 Feb., 426; 11 Mar., 744; 18 Mar., 857; 15

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Apr., 1108; 13 May, 1452; 20 May, 1549; 17 June, 1833; 19 Aug., 482

Edmund Scientific Co.
1959: 9 Oct., 886; 6 Nov., 1221; 27 Nov., 1446; 4 Dec., 1506
1960: 8 Jan., 69; 19 Feb., 459; 18 Mar., 791; 22 Apr., 1138; 27 May, 1631; 17 June, 1764; 22 July, 259; 26 Aug., 508; 23 Sept., 855

Elgeet Optical Co., Inc.
1959: 13 Nov., 1301
1960: 22 Jan., 186; 18 Mar., 793; 20 May, 1487; 10 June, 1699; 22 July, 185; 5 Aug., 318; 19 Aug., 491; 2 Sept., 631; 16 Sept., 698; 7 Oct., 914

Graf-Apsco Co.
1959: 23 Oct., 1121; 4 Dec., 1595
1960: 22 Jan., 237; 19 Feb., 563; 22 Apr., 1244; 20 May, 1549; 9 Sept., 686; 23 Sept., 816

Harvard Apparatus Co., Inc.
1959: 4 Dec., 1605

International Equipment Co.
1959: 25 Dec., 1730, 1731

Leitz, E., Inc.
1959: 23 Oct., 1033; 18 Dec., 1674

Mistaire Laboratories
1959: 27 Nov., 1489; 4 Dec., 1608; 11 Dec., 1660; 18 Dec., 1714

Nuclear-Chicago Corp.
1959: 27 Nov., 1492; 11 Dec., 1672
1960: 19 Feb., 570; 29 Apr., 1332; 8 July, 104

Packard Instrument Co., Inc.
1960: 29 Apr., 1286; 10 June, 1704; 5 Aug., 322; 16 Sept., 706

Picker X-Ray Corp.
1960: 12 Aug., 379; 23 Sept., 775

Pioneer Scientific Corp.
1960: 16 Sept., 703

Science Materials Center
1959: 6 Nov., 1217

Technical Measurement Corp.
1960: 19 Feb., 476; 16 Sept., 704

United Scientific Co.
1959: 30 Oct., 1201
1960: 22 Jan., 176; 4 Mar., 677; 1 Apr., 996; 15 Apr., 1064; 22 Apr., 1246; 13 May, 1454; 20 May, 1562; 15 July, 156; 16 Sept., 748; 30 Sept., 902

Welch, W. M., Manufacturing Co.
1959: 4 Dec., 1589
1960: 1 Jan., 51; 3 June, 1685

Will Corp., Bronwill Scientific Div.
1960: 18 Mar., 864; 8 Apr., 1055; 9 Sept., 680

SURVEYING INSTRUMENTS

Wild Heerbrugg Instruments, Inc.
1959: 9 Oct., 890; 23 Oct., 1046; 6 Nov., 1218; 20 Nov., 1435; 4 Dec., 1530; 18 Dec., 1678
1960: 8 Jan., 68; 22 Jan., 230; 29 Jan., 263; 12 Feb., 380; 26 Feb., 614; 11 Mar., 694; 18 Mar., 796; 8 Apr., 1010; 22 Apr., 1260; 13 May, 1400; 27 May, 1627; 10 June, 1700; 24 June, 1858; 8 July, 95; 22 July, 250; 12 Aug., 378; 19 Aug., 486; 26 Aug., 552; 9 Sept., 685; 23 Sept., 828

Zeiss, Carl, Inc.
1960: 26 Feb., 621

SYRINGES AND ACCESSORIES

Hamilton Co., Inc.
1959: 9 Oct., 930; 23 Oct., 1136; 25 Dec., 1764
1960: 18 Mar., 852; 25 Mar., 944; 22

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A modification of the regular Determatube LDH (reading at 340 mμ), which makes it possible to determine LDH activity in the visible light region (600 mμ) using any standard laboratory colorimeter.

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Apr., 1234; 22 July, 253; 26 Aug., 513; 23 Sept., 831

Phipps & Bird, Inc.
1960: 25 Mar., 943; 1 Apr., 997; 8 Apr., 1051

Scientific Industries, Inc.
1960: 23 Sept., 834

TACHOMETERS

Sticht, Herman H., Co., Inc.
1959: 23 Oct., 1137

TAPE RECORDERS

Precision Instrument Co.
1960: 23 Sept., 852; 7 Oct.. 963

TEACHING MACHINES

Foringer & Co., Inc.
1959: 4 Dec., 1603

TELESCOPES

Edmund Scientific Co.
1959: 9 Oct., 886; 27 Nov., 1446; 4 Dec., 1506
1960: 8 Jan., 69; 19 Feb., 459; 18 Mar., 791; 27 May, 1631; 17 June, 1764; 22 July, 259; 26 Aug., 508; 23 Sept., 855

United Scientific Co.
1959: 30 Oct., 1201; 6 Nov., 1266; 4 Dec., 1584
1960: 8 Jan., 114; 6 May, 1388; 5 Aug., 364

Zeiss, Carl, Inc.
1960: 26 Feb., 621

TEMPERATURE CONTROL EQUIPMENT

Brinkmann, C. A., & Co., Inc.
1959: 6 Nov., 1219, 1270; 4 Dec., 1609
1960: 5 Feb., 361; 22 Apr., 1241; 20 May, 1549

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Baird-Atomic Flame Photometer makes fast, precise biological analyses reproducible to ±0.5%
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Metal	meq/l	mg%	ppm
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K	0.0025	0.001	0.01
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F & M Scientific Corp.
1960: 18 Mar., 766; 22 July, 252

Instruments for Research and Industry
1959: 23 Oct., 1148
1960: 19 Feb., 546; 18 Mar., 878

National Appliance Co.
1960: 8 Apr., 1056

Will Corp., Brownwill Scientific Div.
1959: 23 Oct., 1110
1960: 19 Feb., 450; 22 Apr., 1146; 17 June, 1769; 26 Aug., 507

THERMOMETERS

Greiner, Emil, Co.
1960: 18 Mar., 858

Instruments for Research and Industry
1960: 22 Apr., 1266; 20 May, 1566

New York Laboratory Supply Co., Inc.
1959: 20 Nov., 1431

Tri-R Instruments
1959: 23 Oct., 1137
1960: 18 Mar., 864; 23 Sept., 816

Yellow Springs Instrument Co., Inc.
1960: 23 Sept., 818

TIMERS

Foringer & Co., Inc.
1959: 4 Dec., 1603

Standard Scientific Supply Corp.
1959: 4 Dec., 1596
1960: 22 Apr., 1254

TISSUE CULTURE APPARATUS

Bellco Glass Inc.
1959: 23 Oct., 1129; 13 Nov., 1368; 4 Dec., 1507; 18 Dec., 1713
1960: 8 Jan., 113; 22 Jan., 255; 5 Feb., 368; 19 Feb., 539; 4 Mar., 678; 18 Mar., 879; 8 Apr., 1051; 22 Apr., 1243; 6 May, 1385; 20 May, 1542; 3 June, 1689; 17 June, 1842; 8 July, 94; 22 July, 257; 5 Aug., 367; 19 Aug., 482; 9 Sept., 684; 23 Sept., 850; 7 Oct., 970

Falcon Plastics Co.
1960: 24 June, 1860; 1 July, 5

Fisher Scientific Co.
1959: 4 Dec., 1606

Harvard Apparatus Co., Inc.
1959: 13 Nov., 1368

Kontes Glass Co.
1959: 4 Dec., 1588
1960: 22 Jan., 253; 19 Feb., 558; 18 Mar., 859; 22 Apr., 1228; 20 May, 1536; 22 July, 252

Nalge Co., Inc.
1960: 26 Aug., 570; 23 Sept., 824

TITRATION EQUIPMENT

Boekel, Wm., & Co., Inc.
1960: 20 May, 1537

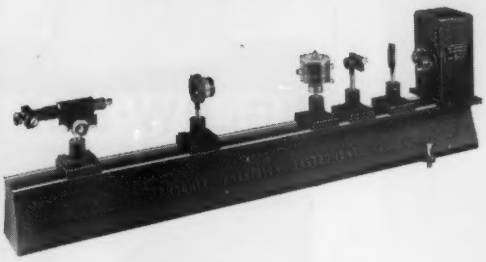
Brinkmann, C. A., & Co., Inc.
1959: 6 Nov., 1219; 13 Nov., 1363
1960: 22 Jan., 215, 216, 218; 29 Jan., 309; 26 Feb., 613; 4 Mar., 673; 25 Mar., 939; 6 May, 1386

Buchler Instruments, Inc., formerly Laboratory Glass & Instruments Corp.
1960: 26 Aug., 572

California Laboratory Equipment Co.
1959: 9 Oct., 929; 6 Nov., 1267; 11 Dec., 1666

Coleman Instruments, Inc.
1959: 18 Dec., 1716
1960: 15 Jan., 166; 20 May, 1560; 23 Sept., 836

Direct Measurement of Difference in Refractive Index



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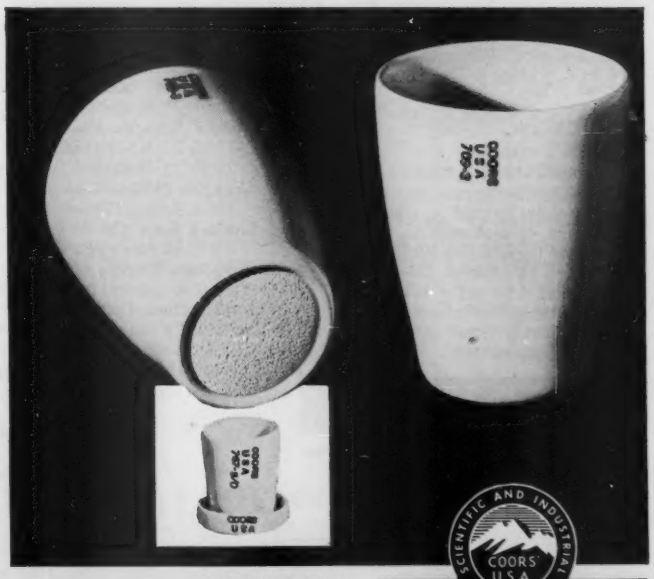

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Drugs	Milk Solids
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Fly Ash	

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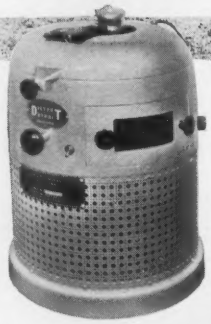

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Company_____

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Corning Glass Works
1960: 8 Apr., 1011; 13 May, 1450
Doerr Glass Co.
1959: 13 Nov., 1283; 4 Dec., 1499
Greiner, Emil, Co.
1960: 22 July, 246
Hamilton Co., Inc.
1960: 22 Jan., 254; 20 May, 1558
Instrumentation Associates
1960: 19 Feb., 556; 23 Sept., 840
Kimble Glass Co.
1959: 2 Oct., 823
Kontes Glass Co.
1959: 16 Oct., 985; 30 Oct., 1204; 6 Nov., 1220
LaPine, Arthur S., and Co.
1960: 22 Jan., 250; 23 Sept., 822
Nalge Co., Inc.
1960: 20 May, 1564; 17 June, 1824; 22 July, 248
Polarad Electronics Corp.
1960: 19 Feb., 469; 18 Mar., 787; 20 May, 1475; 22 July, 187
Precision Scientific Co.
1960: 22 Jan., 245
Sargent, E. H., & Co.
1960: 18 Mar., 794; 23 Sept., 780
Scientific Industries, Inc.
1960: 23 Sept., 834
Standard Scientific Supply Corp.
1960: 17 June, 1843
Thomas, Arthur H., Co.
1959: 13 Nov., 1372
1960: 5 Feb., 372
Will Corp.
1960: 22 Apr., 1267; 27 May, 1625

TRANSDUCERS, PRESSURE

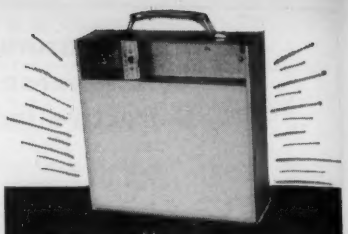
Sanborn Co.
1959: 11 Dec., 1623

TUBE FITTINGS

Beckman Instruments, Inc., Scientific and Process Instruments Div.
1960: 23 Sept., 826

VACUUM EQUIPMENT

Ace Glass, Inc.
1960: 22 July, 237
Blickman, S., Inc.
1960: 20 May, 1557
Central Scientific Co.
1959: 27 Nov., 1485
1960: 25 Mar., 941; 29 July, 309
Granville-Phillips Co.
1960: 7 Oct., 970
Greiner, Emil, Co.
1960: 18 Mar., 881
Hevi-Duty Electric Co.
1960: 8 Jan., 111; 4 Mar., 677
Kimble Glass Co.
1960: 22 Jan., 183; 11 Mar., 689
LaPine, Arthur S., and Co.
1960: 18 Mar., 842; 20 May, 1550
National Appliance Co.
1959: 13 Nov., 1353
New York Air Brake Co., Kinney Vacuum Div.
1960: 19 Feb., 533; 18 Mar., 849; 22 Apr., 1225; 17 June, 1819; 19 Aug., 483
New York Laboratory Supply Co., Inc.
1960: 17 June, 1819
Philips Electronic, Inc.
1960: 17 June, 1766, 1767
Precision Scientific Co.
1960: 17 June, 1828; 22 July, 230



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Smith, Arthur F., Inc.
1960: 17 June, 1844
VirTis Co., Inc.
1959: 23 Oct., 1038
Welch, W. M., Manufacturing Co.
1959: 6 Nov., 1267

VALVES

Granville-Phillips Co.
1960: 7 Oct., 970
New York Air Brake Co., Kinney Vacuum Div.
1960: 19 Feb., 533; 18 Mar., 849: 22 Apr., 1225; 17 June, 1819; 19 Aug., 483
Phipps & Bird, Inc.
1960: 16 Sept., 749; 23 Sept., 814

VISCOMETERS

Ferranti Electric, Inc., Electronics Div.
1960: 18 Mar., 861
Fish-Schurman Corp.
1959: 4 Dec., 1608
Polarad Electronics Corp.
1960: 19 Feb., 470; 18 Mar., 788; 20 May, 1475; 22 July, 187

VOLTAGE CONVERTERS

Central Scientific Co.
1960: 15 July, 160

VOLTAGE TESTERS

Sorensen & Co.
1960: 22 Apr., 1223

WARBURG APPARATUS

Gilson Medical Electronics
1959: 11 Dec., 1665
1960: 10 June, 1746; 8 July, 97
Will Corp., Bronwill Scientific Div.
1959: 16 Oct., 989
1960: 19 Feb., 450; 22 Apr., 1146; 17 June, 1769; 26 Aug., 507

WARING BLENDORS

Waring Products Corp.
1959: 30 Oct., 1202, 1203
1960: 8 Apr., 1007; 13 May, 1455; 10 June, 1743; 23 Sept., 825

WASHERS, GLASSWARE

Fisher Scientific Co.
1959: 16 Oct., 992

WATER BATHS

LaPine, Arthur S., and Co.
1960: 19 Feb., 560; 26 Aug., 556
National Appliance Co.
1960: 18 Mar., 850; 9 Sept., 688

WATER PROCESSING SYSTEMS

American Sterilizer Co.
1960: 22 Apr., 1159

X-RAY EQUIPMENT

Philips Electronics, Inc.
1959: 13 Nov., 1284, 1285
1960: 17 June, 1766, 1767
Radio Corporation of America
1959: 23 Oct., 1018; 4 Dec., 1518

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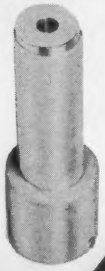

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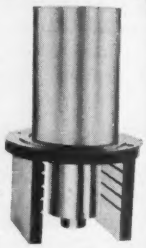

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Badger Research Corp.
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Dyna Slide Co.
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Electro-Medical Laboratory, Inc.
South Woodstock 2, Vt.

Esbe Laboratory Supplies
459 Bloor St. West, Toronto, Canada

Food and Drug Research Laboratories, Inc.
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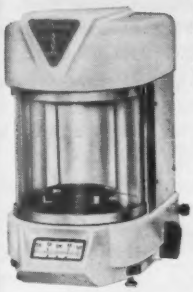

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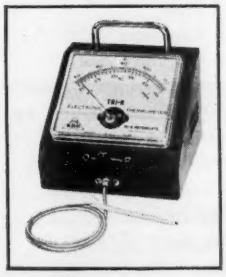

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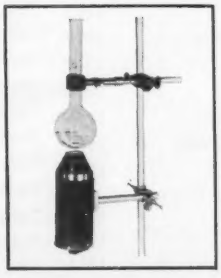

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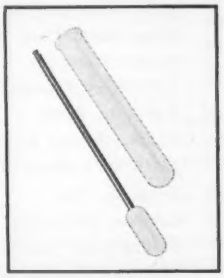

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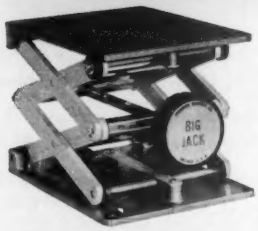

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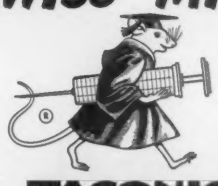

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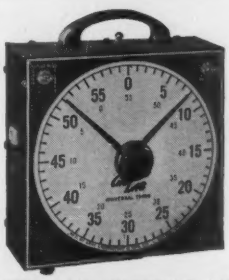

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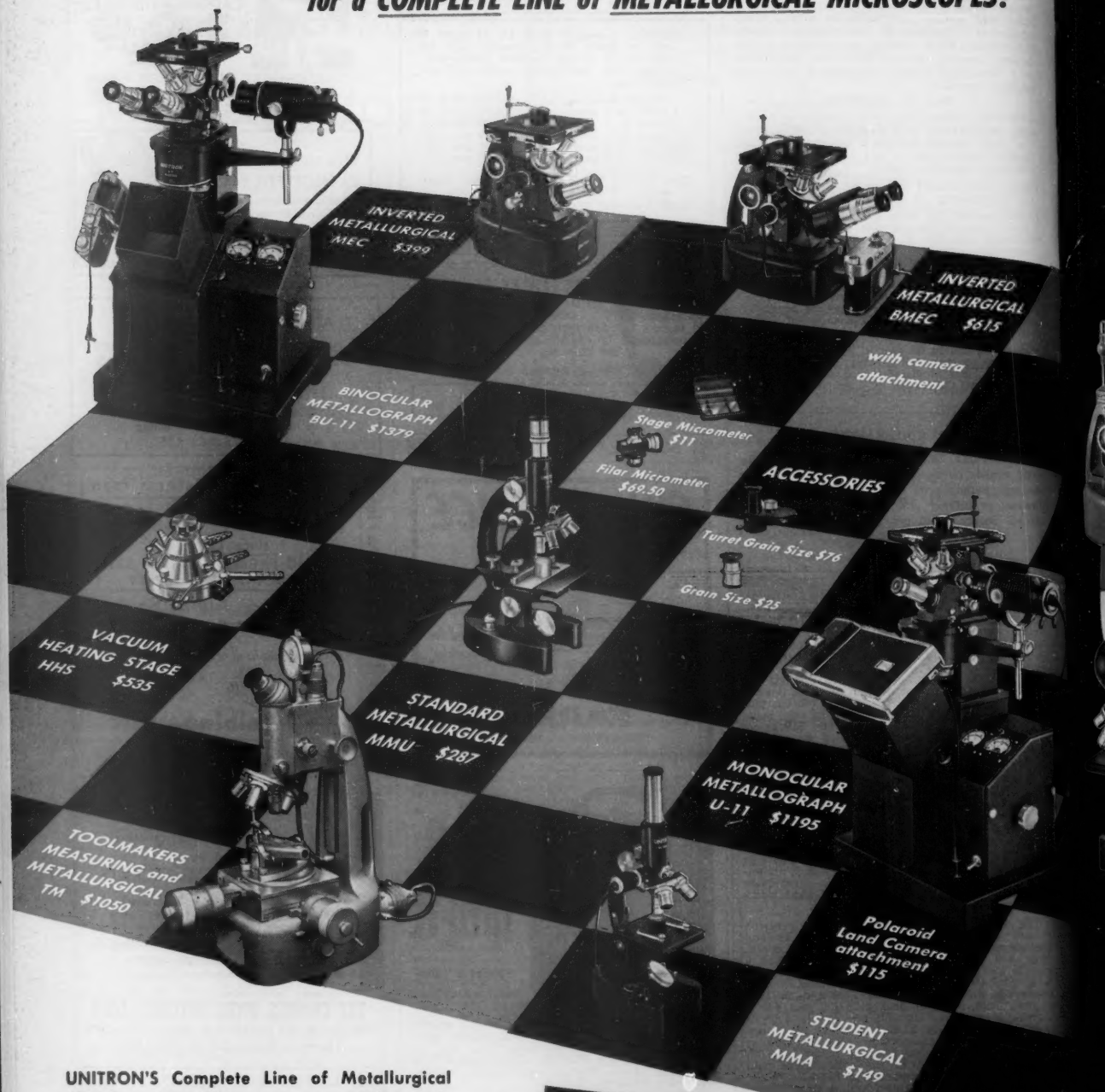

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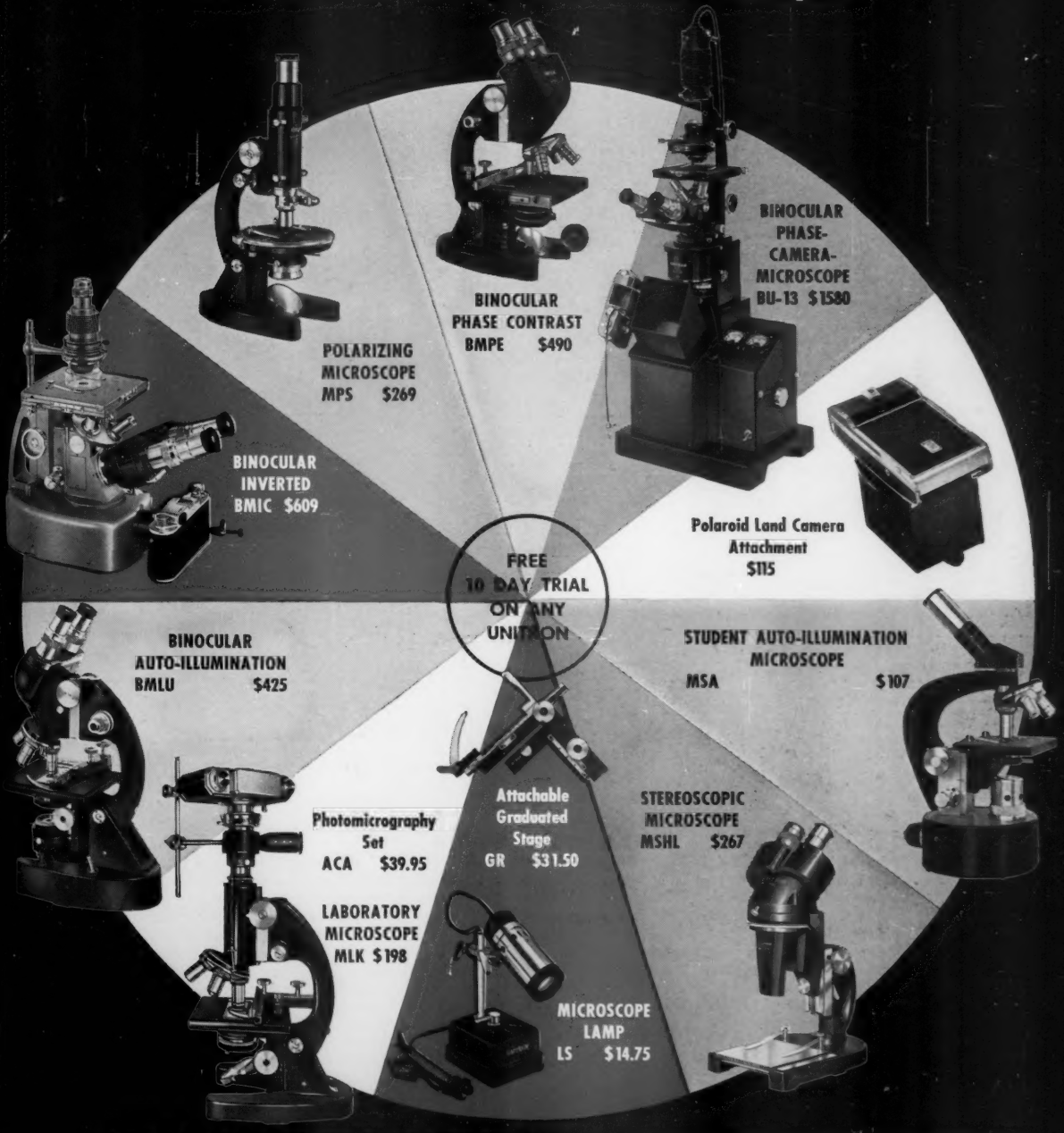
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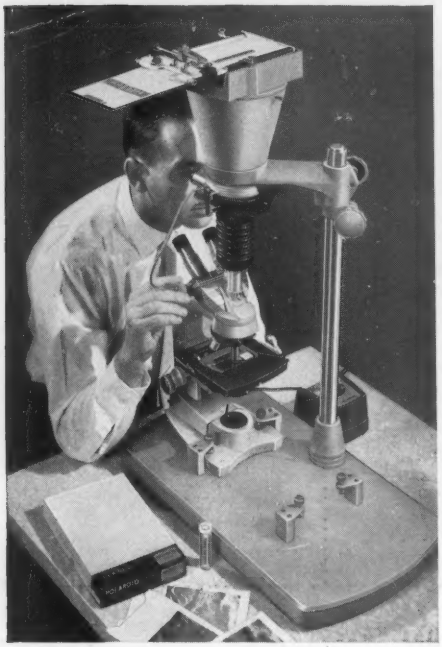

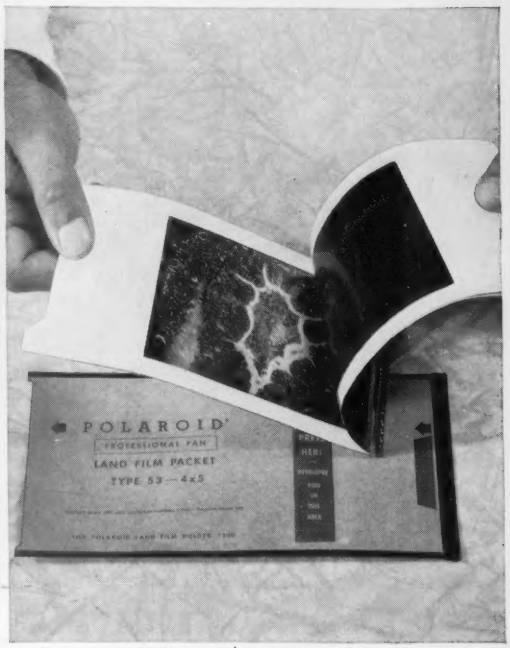

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